JUNE 1957

THE WELDING JOURNAL

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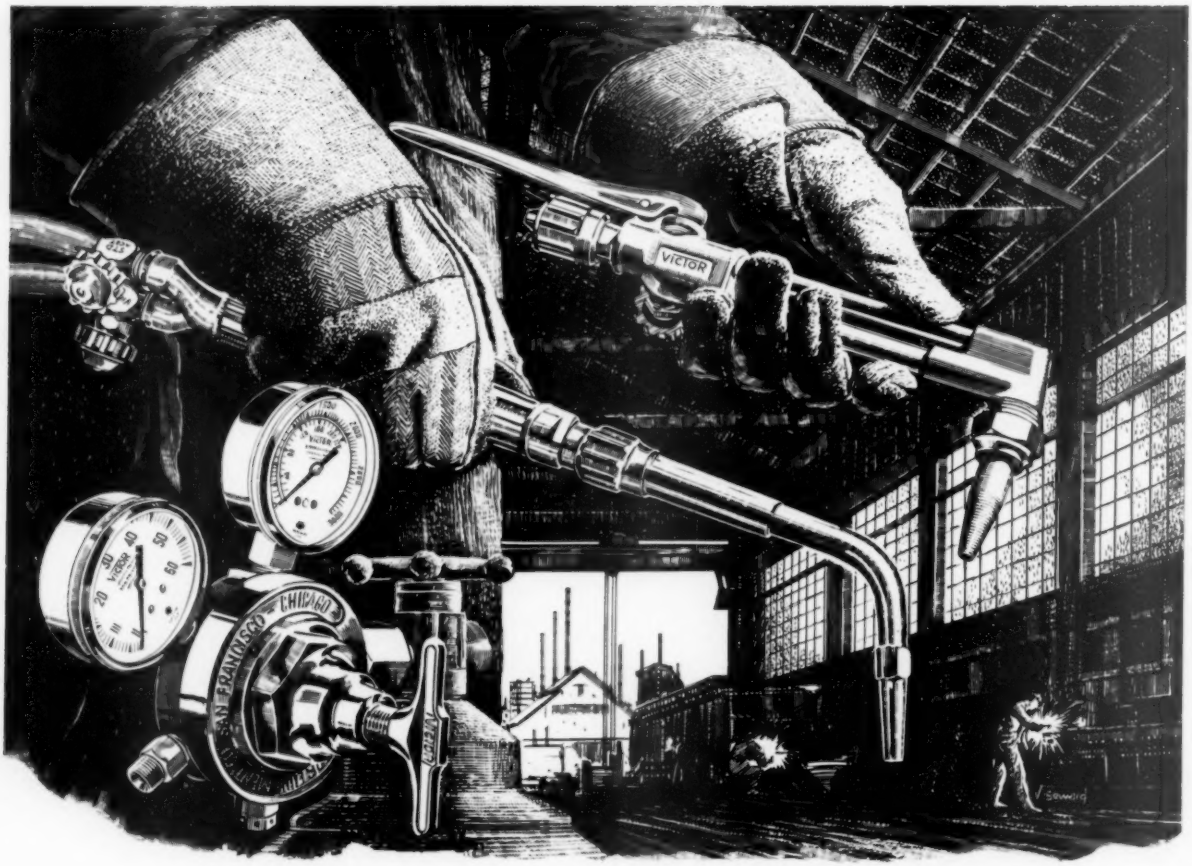

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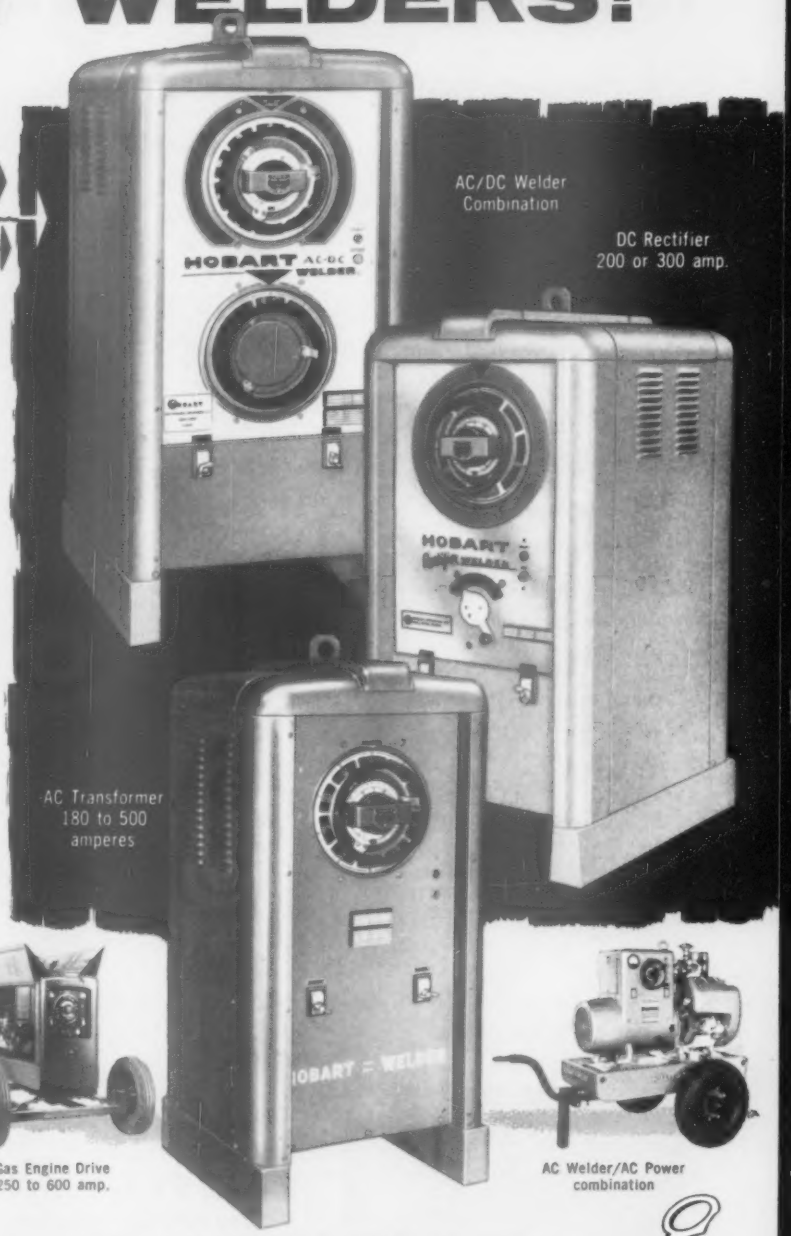

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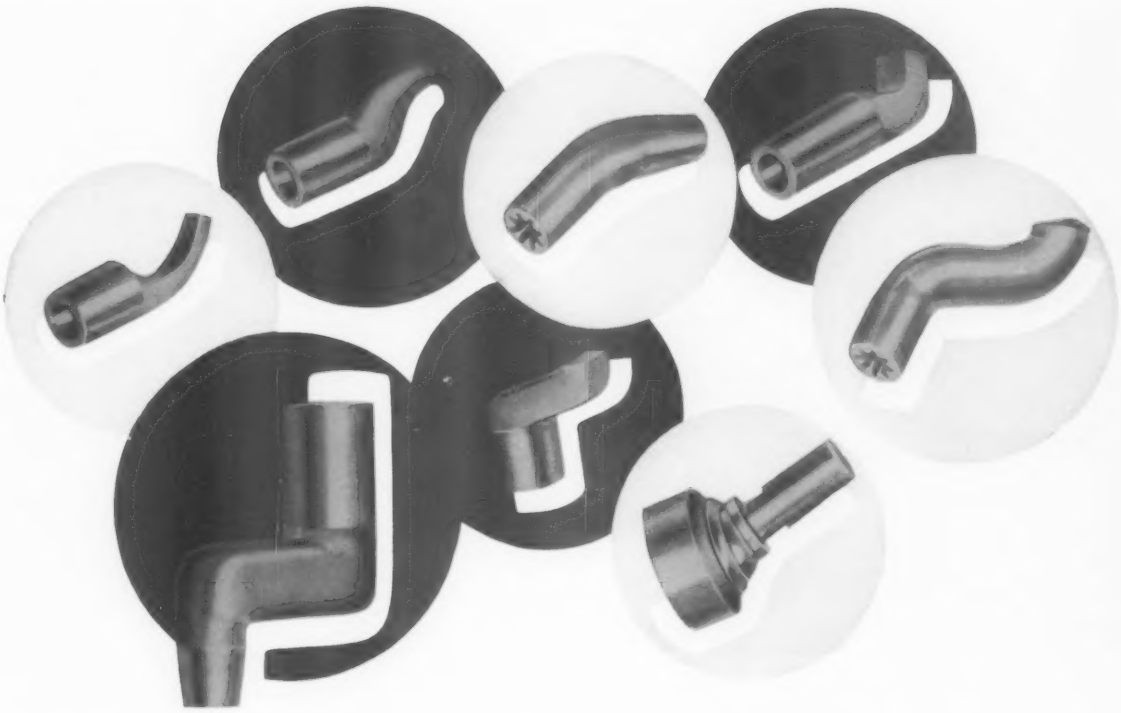

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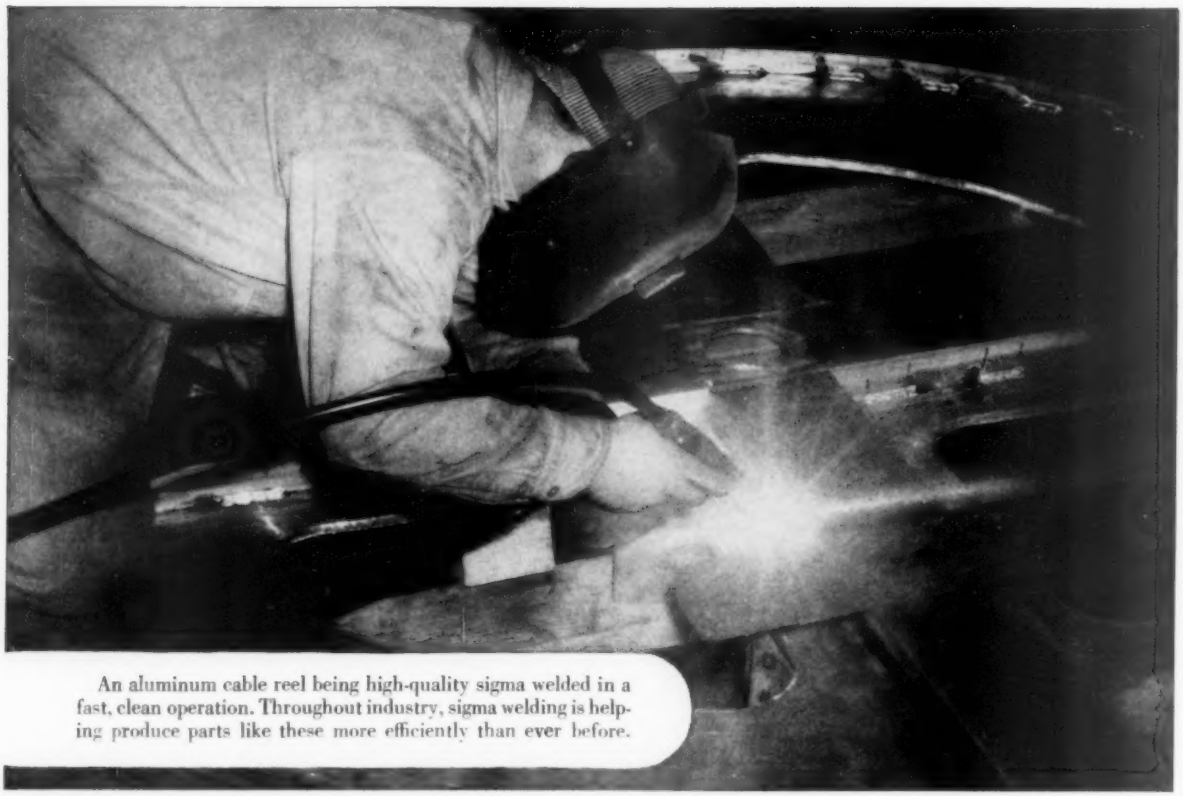

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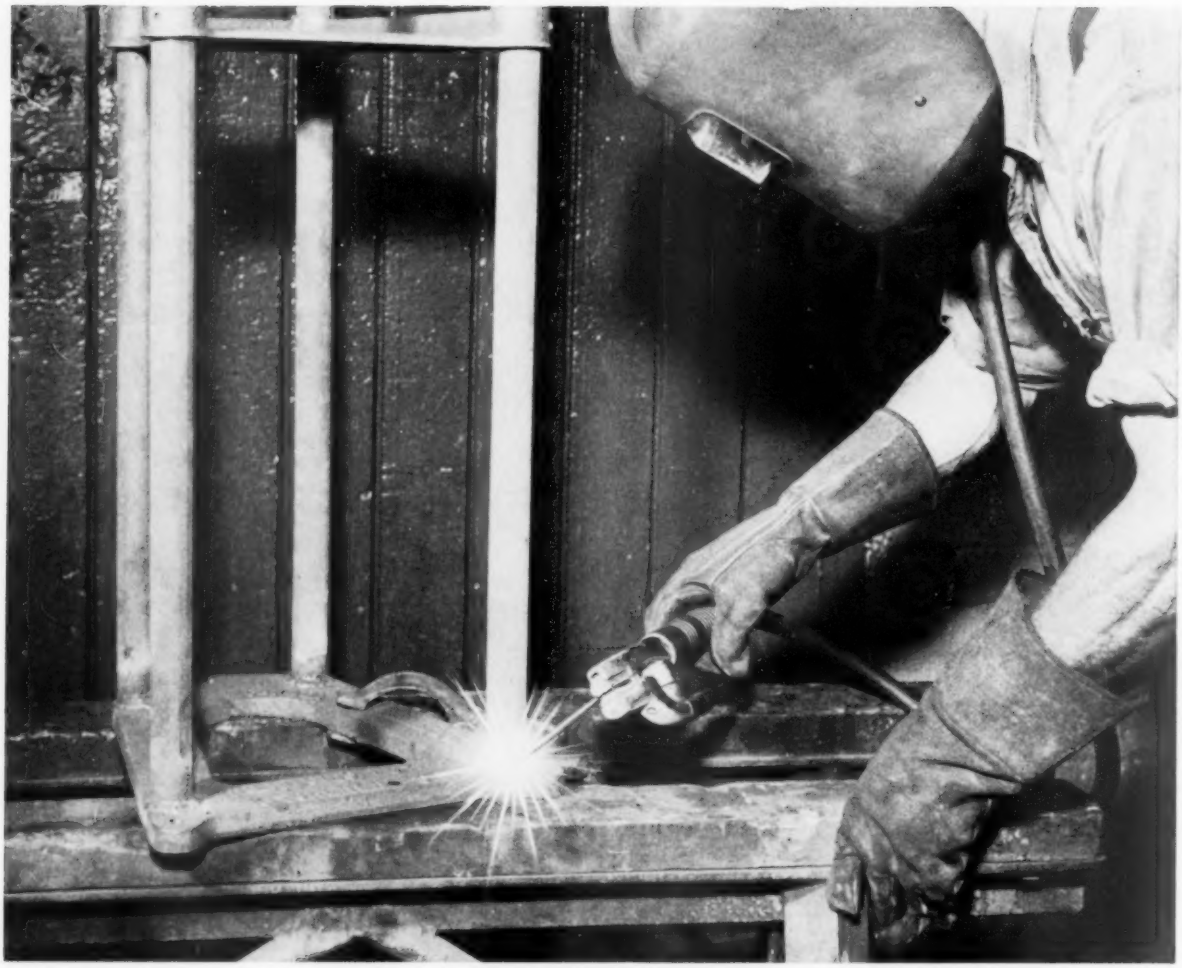

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MAKING PROGRESS

The AMERICAN WELDING SOCIETY is the active source of unique liaison and neutral leadership that combines all efforts in the field of welding and promotes its practical use to the entire metal-working industry. It is proud of its record and its part in the progress to date, and will continue in its given course with even greater efforts, thanks to its 12,000 active and interested members.

Our SOCIETY has done much through volunteered time, expense and effort—to initiate, develop and secure adoption of welding codes, standards and specifications. The development of a code or standard requires diligent search, learning and the recognition of experience, so that its ultimate application will constitute a practical safeguard for the industry, thereby assuring progress within the order of the trend and the need.

The formulation of new codes and the revision of old ones are not, of course, our only objectives at the present time. The furthering of the general technical knowledge, the improvement of the available processes and techniques, the bringing forth of new standards and publications and the development of practical information for the man in the shop are receiving our constant attention.

Education is another vital field in which our SOCIETY is now actively engaged. A comprehensive program is now under way to promote greater welding interest among students and faculty in high schools, trade schools, technical institutes and engineering colleges. This endeavor holds great promise for a successful future.

With stepped-up activities in all related fields, welding will continue to lead the way in solving fabrication problems. The end results will, no doubt, show greater economic and engineering design progress. The high-strength alloys required by such rapidly expanding fields as nuclear physics, aeronautics, guided missiles and jet propulsion, will make the application of welding more mandatory and applicable as time goes on.

With the combined teamwork and efforts of metal producers, fabricators, welding equipment manufacturers, welding suppliers and usable standards and processes, giant strides are being made toward a more universal use of welding to the benefit of all concerned.

However, while welding is making progress and our SOCIETY has a bright future, we still have a long road to travel before we reach our ultimate goal.

Clarence P. Sander
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Welding and assembly bay at Alloy Fabricators plant

IMPORTANT PROCEDURES IN PROPER WELDING SHOP MANAGEMENT

BY JOSEPH L. FORTUNATO

Shop procedures considered necessary for obtaining consistently high-grade welding performance are outlined by the author

ABSTRACT. With the advent of the atomic era, pressure vessel fabricators have become increasingly aware of the necessity to maintain extremely close control of materials and workmanship. Shop supervision must be kept abreast of the ever-changing methods and processes being developed to produce high quality welding. Therefore, it has been necessary to set up certain important fabrication and welding procedures consistent with good shop management practice to achieve the desired results.

Basically, a clear understanding of the problems on hand is extremely desirable. This can best be accomplished by production planning meetings with shop supervision to discuss fabrication methods, welding procedures and interpretation of specifications and drawings.

Proper identification of materials, including base metals and welding electrodes, is essential particularly in a welding shop where a variety of alloys are used. Qualification of welders, use of the proper welding techniques and selection of equipment are all important factors attributing to quality welding. Use of automatic welding equipment further reduces the margin of human error.

Liquid dye-penetrant examination, visual inspection, test plates, radiography, hydrostatic and mass spectrometer testing round out the basic important procedures for maintaining proper control.

Standard procedures tie in all aspects of the welding operation from initial preparation to final assembly. Control of these various operations not only produce consistently high quality workmanship but also increase shop efficiency for repetitive operations.

Joseph L. Fortunato is Production Manager, Alloy Fabricators Division, Continental Copper and Steel Industries, Inc., Perth Amboy, N. J.

Presented at 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8-12.

Preliminary Planning

The initial step required is to maintain an informed staff of shop supervision fully cognizant of the objectives. This can best be achieved by conducting regular production planning meetings attended by the supervisory personnel of the production, fabrication, welding and inspection departments. The production manager outlines the job requirements including a review of material, design and fabrication specifications, design details and other pertinent data. Particular attention is placed on the proposed welding procedure and the weld quality specified. Production schedule requirements and actual fabrication and welding procedures are determined. Further, the need for any additional equipment facilities are reviewed. Welding procedures are either selected from currently active procedures or

Fig. 1 Layout foreman reviewing blue print details and checking plate layout

Fig. 3 Punch press adapted with dies for forming flange on head. Completed dished and flanged head shown in background

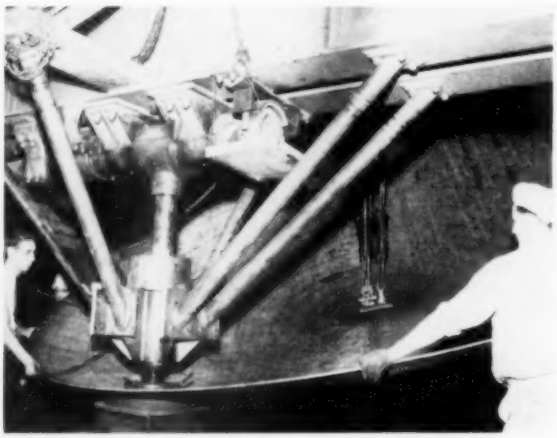

Fig. 2 Specially designed dishing machine bumping head plate. Material: $^1/_2$ in. thick, 304LC stainless steel

Fig. 4 Heat numbers being etched on sample coupon with electric pencil

new qualification test plates involving the use of the applicable welding procedures are made. No production work is performed until both the welding procedure and the welders or welding operators have been qualified. Proper planning eliminates undue lost time since there will be very little or no indecision during the fabricating cycle and the shop supervisors can impart the same information to their subordinates. Special attention is given to both the number of man-hours estimated to produce the particular piece of equipment and the requisitioning of materials particularly if the material involved is a high-priced austenitic stainless steel, Monel, Inconel and the like. Depending upon the type of equipment fabricated, the cost generally averages out to a fifty-fifty basis—50% labor and burden and 50% material. Therefore, a review of the labor man-hours for each operation involved aids shop supervision to determine whether current methods are adequate to perform according to schedule. Prudent material requisitioning directly affects costs since many labor man-hours can either be saved or unnecessarily wasted by the incorrect selection of the size or shape of plate. Not only must shop supervision be qualified to handle all of the technical aspects of equipment manufacture but they must also be well versed in all phases of shop costs and their control. One of the best ways for shop supervision to keep abreast of new trends in the welding field is to attend the regular monthly meetings at the local Welding Society Section.

Informed shop personnel is a primary factor affecting production efficiency and, equally important, quality of workmanship, since in the majority of vessel fabrication shops the labor input constitutes a very large proportion of the over-all operation. It has been our experience that it does not suffice to merely submit specifications and drawings to shop supervision without adequate planning.

Material Expediting

Following the production planning meeting, the complete bill of material is reviewed by a material expe-

diter to determine any lacking items which are expedited into the plant. Material shortages, however, small, are a continuous source of trouble which can curtail production of equipment and increase fabrication costs. Consequently, every item of material is given equal attention including every bolt, nut and gasket. Particularly in a jobbing shop where fifty odd contracts containing from twenty to several hundred items of material are processed monthly, it is no mean feat to coordinate purchased material with the production schedules. Material is expedited several months in advance of contemplated production by a standard procedure involving the use of vendor acknowledgments, follow-up postal card, periodic letters, telephone calls and, if need be, direct personal contact with the vendors. Furthermore, the receipt of every main item of material must be accompanied by the corresponding mill-test material-certification reports showing chemical analysis and physical properties. The mill test reports are analyzed by the production office to ascertain their conformance with the appropriate ASTM specification. Receipt of material specifications are as important as the material itself, the reason for which will be discussed under the section of material control. Material shortages cause production delays, slow downs and increased labor costs and are equally serious in a jobbing shop as in a production shop producing a standard product.

Layout and Forming

The procedure for plate layout for a vessel follows a standard pattern. Blue prints, a copy of the bill of material and a copy of the job specifications are submitted to the layout shop foreman with a shop work order authorizing start of production. Material is requisitioned from plate stores and full-size paper layouts for all fittings and intricate forms are made and transferred to the plate. Considerations of minimum welding and avoidance of seams at connections are taken into account. Prior to any cutting or forming operations, the plate layouts are checked by the layout foreman. Figure 1 illustrates this procedure being carried out. Accuracy of plate layouts is continuously stressed since it will avoid waste of material and subsequent delays and lost time during fabrication. In order to reduce accumulations of tolerances, all measurements are taken from a common base line usually a part of the vessel from which actual measurements can be made. Allowance for weld shrinkage during fabrication is also taken into account. Standard allowances for shrinkage are set up and applied; they are based upon past experience considering thickness of material and shape of part. Economy of material is important particularly when fabricating vessels of hard-to-obtain items of stainless steel, Monel and other alloy steels.

Cold forming of shell plates, head plates and fittings in press brakes, power presses and plate forming rolls is generally employed. Hot forming is performed on plate requiring severe working in a single operation. After severe cold working of material, it is necessary to either stress relieve (at 1500° F and furnace cool) or solution heat treat (1950–2050° F soak and water quench) to restore ductility and normal structure to the metal. Torispherical head forming to ASME Code requirements, particularly for diameters ten feet and over, requires knowledge of the forming qualities of metals and know-how developed over many years of experience. The torispherical shape in the head is formed by a "bumping operation" on a deep throat press or equipment especially designed for this operation (see Fig. 2). Figure 3 is an illustration of a power press machine set up for flanging an 11-ft diam head to ASME specifications. The material thickness of the head shown in Fig. 3 is $^1/_4$-in. thick type 304L material. The equipment used is a power punch press equipped with suitable flanging dies. All forming operations are designed to minimize tears, cracks and any irregularities on plate edges subsequently to be welded. Forming accuracy within the limits of the equipment is maintained to reduce to a minimum the amount of refitting and shaping prior to the welding operation.

Control of Material

All major items of material, including head plates, shell plates, large fittings and all internals (when called for) are identified with their proper corresponding heat numbers. Heat numbers, obtained from material certification reports, are transferred to the plates by means of stamping or, preferably, by electric etching since many specifications do not allow the use of metal stamping (see Fig. 4). Proper identification of materials prevent any inadvertent substitutions and are required to maintain adequate inspection records during fabrication. A further precaution is taken for identification of material by marking the different stainless steels with a color code marking, such as:

Green for Type 347 stainless steel
Blue for Type 316 stainless steel
Yellow for Type 304 stainless steel
Red for Type 310 stainless steel
Black for Monel
Red and white for nickel

Use of the color code method is a simple and quick visual means to check material types and is an added precaution against inadvertent use of incorrect material.

The chemical analysis shown on the face of the material certification reports supplied by the mills are of each melt of steel taken from a test ingot during the pouring of the melt. This is known as a ladle analysis. Usually, ladle analyses are adequate but, on occasion, depending upon the service of the equipment, a check analysis performed by an independent laboratory is made from a coupon (approximately 2 x 2 in.) of the plate in the as-rolled condition. The chemical composition thus determined must conform to the applicable ASTM requirements. Quite often specifications may call for corrosion evaluations of the base material prior to fabrication. This procedure, known as the Huey test, involves the immersion of a 1 x 1-in. coupon of plate material in boiling nitric acid for five 48-hr

periods and the corrosion rate evaluated in inches per month determined. Rates of 0.0020 to 0.0025 in. per month are generally acceptable.

As was pointed out under the section on Production Planning, no production work is performed until both the welding procedure and the welders or welding operators have been qualified. Equally important is the receipt of mill test reports. No production work is performed until the required material certification reports are reviewed and checked and, where applicable, production is held up pending receipt of check analysis and/or Huey test results. Too much emphasis cannot be placed upon proper control of material since failure of a check analysis and/or Huey test to comply with the applicable specifications may result in replacement of equipment or solution heat treatment of complete assemblies in order to improve corrosion resistance of the material. A review of the chemical and physical analysis, conducting check analysis and Huey tests must be made far enough in advance to prevent curtailment of production.

Welder Qualification

Since most vessels are fabricated to various code specifications, it is our standard practice to qualify all welding operators and welders in accordance with established welding procedures. In order to have complete flexibility within the plant, most of the welders and welding operators are qualified for all procedures that are currently active. It is the duty of the welding foreman to arrange and supervise whatever tests may be required. Figure 5 shows a welder preparing a qualification test plate under the guidance of the welding supervisor who is shown checking amperage in the line. The test plate will be radiographed, cut to specimen size and submitted to an independent laboratory which will conduct the required bend tests. Certified acceptance reports are then kept on file for future reference. In the event a welder or welding operator does not weld to an established procedure within a six-month period, he is obliged to qualify again before he can perform production welding using the particular procedure.

In order to cover the very wide variety of materials fabricated in our plant, the following welding procedures are currently active; they include:

A. *Stainless Steel*
   1. Type 347—Metal-arc Process
   2. Type 316L—Metal-Arc Process
   3. Type 316L—Inert-Gas-Shielded Metal-Arc Process
   4. Type 310—Inert-Gas-Shielded Metal-Arc Process
   5. Type 304L—Metal-Arc Process
   6. Type 304—Metal-Arc Process
   7. Type 430—Metal-Arc Process

B. *Stainless Clad*
   1. Type 316 Clad—Metal-Arc Process
   2. Type 304—Metal-Arc Process

C. *Aluminum 3029*
   1. Grade 3S—Inert-Gas-Shielded Tungsten Arc
   2. Grade 4S—Inert-Gas-Shielded Metal-Arc

D. *Hastelloy*
   1. Hastelloy B—Inert-Gas-Shielded Metal-Arc
   2. Hastelloy C—Metal-Arc Process

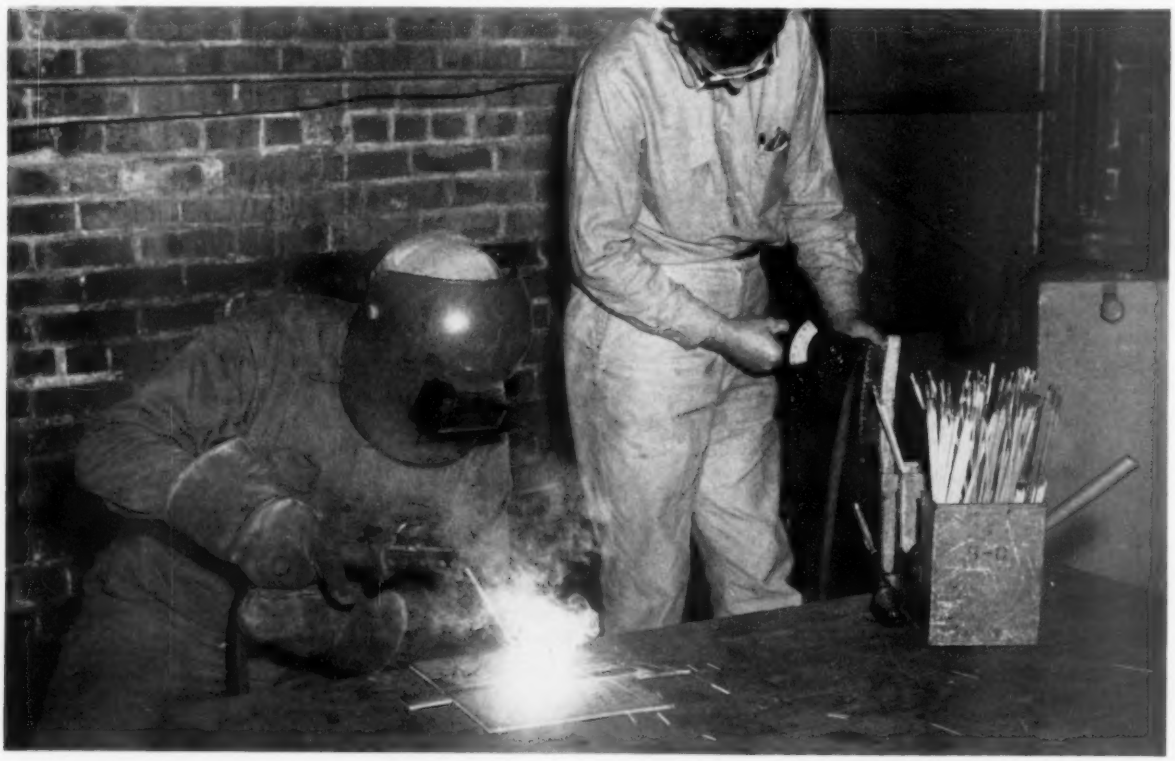

Fig. 5 Welder preparing qualification test plate. Welding foreman checking amperage in line

E. Monel
1. Metal-Arc Process
2. Inert-Gas-Shielded Tungsten-Arc

F. Everdur
1. Inert-Gas-Shielded Metal-Arc Process

G. Cupro-Nickel
1. 70-30 and 90-10 (70-30 Electrode) Inert-Gas-Shielded Metal-Arc Process
2. 70-30 (Monel 60 Electrode) Inert-Gas-Shielded Metal-Arc Process

H. Inconel and Incoloy
1. Inconel—Metal-Arc Process
2. Incoloy—Inert-Gas-Shielded Metal-Arc Process

I. 8½% Nickel Steel
1. Metal-Arc Process—93-50

J. Nickel
1. Metal-Arc Process

K. Nickel Clad
1. Metal-Arc Process

L. Pipe
1. Stainless Steel Pipe Type 347—Inert-Gas-Shielded Metal-Arc Process

Assembly and Welding

Blueprints and job specifications are turned over to a fitter group leader and the pertinent aspects of the job explained by the assembly shop foreman. Prior to any assembly or welding operation, all plate edges are visually examined for defects including laminations and hairline cracks. Plate edges are sanded and cleaned approximately two to three inches from the weld seams and precautions are taken to maintain plate cleanliness within the limits of practicability. Plate edges not previously plane beveled are ground manually with a sheet metal template as a guide. Particular attention is paid to vessel fit-up since uneven and irregular fit-up of plate edges can cause a considerable amount of additional welding and, consequently, distortion. Therefore, all fit-ups between head and shell plates and fittings in vessels are held in strict accordance with standard openings depending upon thickness, size and shape of vessel being fabricated. Proper root spacing is extremely important when automatic welding equipment is contemplated, particularly when welding is to be performed from one side only with no opportunity for back chipping and back welding. Considering the importance of fit-up prior to welding, it is a standard procedure for our shop supervision or shop inspector to examine all alignment of plate edges prior to welding, for cleanliness of joint, gap between plates and size and condition and appearance of tack welds. The sequence of assembly is planned to reduce distortion and residual stresses by making the welds with a minimum of restraint. The longitudinal seams in shell plates are welded in individual courses and re-rolled to maintain roundness tolerances. Head-to-shell alignment is maintained by use of adjustable external bar ring clamps, adjacent to the weld seam.

All welding electrodes are stored in a separate wire crib in accordance with type, size and make. Electrodes are requisitioned to job specifications and, as an added precaution, the wire crib attendant is issued electrode specifications for each job to minimize the possibility of issuing the incorrect type of electrode for the particular contract. All weld wire so issued is preheated in an electric oven at 250-300° F to remove any moisture that may have been picked up during storage. Electrodes whose coatings have not been completely dried out can result in porous welds.

Fig. 6 Weld seam being inspected by fluorescent liquid penetrant method

Wherever possible, welds are made of the double-butt type. Seams are welded from one side and back-chipped or ground on the reverse side. It has been our experience that, although chipping may be a faster method for cleaning out weld seams, there is a distinct possibility of smearing the metal over small imperfections that are later detected during the radiographic examination. Therefore, all cleaning of welds, in our plant, is performed by grinding with special high-cycle equipment. The success or failure of obtaining quality welding depends in a large measure on the removal of all defects in the back grinding operation. Every weld seam so ground is visually examined by the shop inspector. In addition to the visual inspection, an added precaution is taken by checking the weld seam by the fluorescent inspection method. The weld seam is swabbed with a liquid penetrant of essential qualities of good penetration. It is a highly fluorescent oil-base solution, water washable and with sufficient capillary qualities for penetrating into defects. The penetrant is then washed off the surface with a suitable water spray and either a wet or dry developer is applied. The function of the developer is to draw the fluorescent penetrant to the surface to render it more visible under black light (ultra violet) radiation. Thus, minute imperfections invisible to the naked eye, can be detected and repaired. Figure 6 is an illustration of this procedure in process. Where the design of the vessel does

Fig. 7 Test plate used by welder to check performance

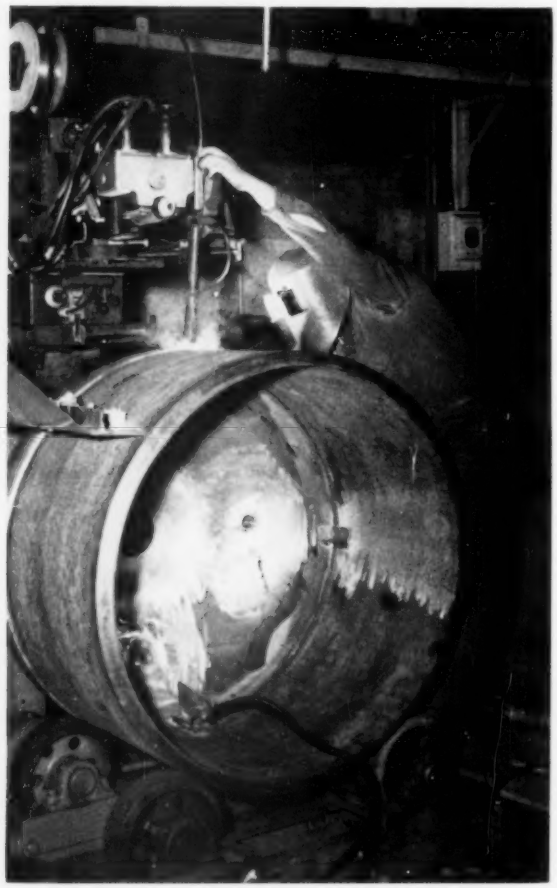

Fig. 8 Vessel being welded utilizing power turning rolls and automatic inert-gas-shielded metal-arc welding equipment

not permit back grinding, the usual procedure is to check the initial and final weld beads by the fluorescent penetrant method. Although continuous examination of welds is time consuming in itself, it provides, in the long run, good insurance against making extensive repairs at the completion of the job.

In order to ascertain weld quality during the course of fabrication, test plates are tacked on to the end of a weld seam and welded in accordance with the procedure specified for the job. The test plate is then examined to determine whether the procedure is being adhered to and radiographed, cut to the proper specimen size and submitted through a guided- or free-bend test. These check test specimens are required at the discretion of the chief inspector whenever he feels that the welder may not be performing to requirements. Figure 7 illustrates this procedure being put into practice. Also, when called for, the weld coupon is submitted to an independent laboratory to determine corrosion evaluation of the deposited weld metal. This method of quality control allows the shop supervision to be continually on the alert for any defective workmanship long before it can become a serious matter and eliminate the necessity to make costly repairs at the conclusion of the welding operation.

Use of Automatic Welding Equipment

Wherever applicable, automatic and semiautomatic positioning and welding equipment is utilized to reduce human error to a minimum. However, it should be pointed out that use of automatic equipment requires extreme care in the initial setup. Root spacings must be uniform, plate edges clean and equipment in perfect operating order. Where the inert-gas-shielded metal-arc process is used, the gas flow must be accurately controlled and the welding wire clean and properly wound on suitable reels. A malfunctioning of any one of these factors can seriously affect the weld quality. However, proper control of these same variables will produce consistently good welds of X-ray quality and reduce the total over-all cost of fabrication. Figure 8 shows a vessel (ultimately used for a rocket test program) being welded with the use of automatic turning tank rolls and automatic inert-gas-shielded metal-arc welding equipment. The vessel shown is of $1^1/_2$-in.

Fig. 9 $^7/_{16}$-in. aluminum shell being welded utilizing semiautomatic inert-gas-shielded metal-arc welding equipment and power turning rolls

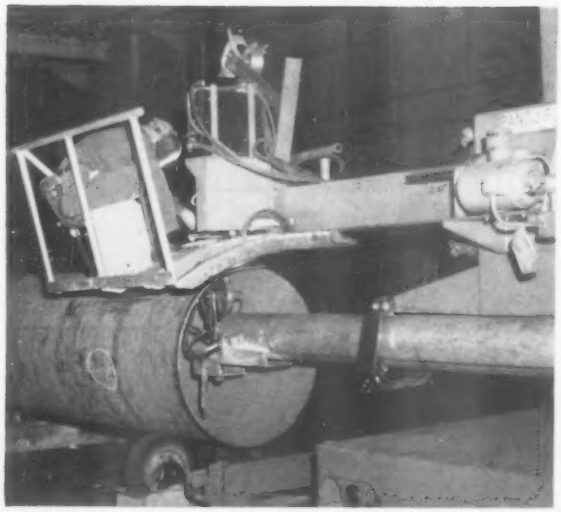

Fig. 10 Automatic welding of longitudinal seam. Note use of water cooled roller arrangement

thickness, Type 347 stainless steel, with all seams radiographed 100% and hydrostatically tested at 3300 psi. Welding time was reduced by 60% by use of this procedure instead of manual-arc welding. Application of semiautomatic equipment is illustrated in Fig. 9. The vessel shown is of $^{7}/_{16}$-in. thickness, Type 3S aluminum, being fabricated to ASME Code, with all weld seams fully radiographed. The equipment used is of the inert-gas-shielded metal-arc type.

Automatic turning tank rolls, welding positioners and welding manipulators are essential equipment in a welding shop producing high quality workmanship at the lowest possible cost. An additional advantage of positioning equipment is that, in most instances, welding can be performed in the flat position. Welding in the overhead, vertical or horizontal position is kept to a minimum.

Development of New Welding Techniques

One of the most costly operations in vessel fabrication is back chipping and rewelding. Therefore, we are constantly searching for better methods to eliminate such costly operations. Several years ago, our plant was one of several stainless-steel fabricators required to produce welded pipe of the highest quality of workmanship for a government agency. Pipe sizes ranged from 3- to 14-in. IPS size, Schedule 10 and Schedule 40 of Type 304L and 309 Cb material in lengths of 10 feet and greater. Specifications called for stringent X-ray quality and conformance with all other A.S.T.M. requirements for seamless pipe. Up to that time we did not have any welding procedure which would satisfy these requirements. After considering various procedures, we finally developed a welding method which resulted in the production of several hundred thousand feet of piping in conformance with the specifications with an over-all rejection rate of $1^{1}/_{2}$%. Welding was accomplished by the inert-gas-shielded metal-arc process. In order to eliminate the necessity of any back welding, a water-cooled copper backup bar was utilized. The bar traveled simultaneously with the welding head over the length of pipe and the inside weld metal was protected with inert gas fed through the copper element. A 100% penetration was obtained and was controlled to a build-up not exceeding $^{1}/_{16}$ in. The success of this method led us to expand on this idea and to apply it to larger weldments—mainly pressure vessels. Figures 10, 11 and 12 shows the equipment set up to apply this welding technique to large vessels. An automatic welding head is mounted on a welding manipulator boom geared to travel at welding speeds from 6 to 64 ipm. Attached to the boom is an auxiliary pipe supporting a water-cooled copper roller. During the welding operation, a jet of inert gas is directed at the top of the roller and impinged on the inside weld penetration. The roller, which has an adjustment of 90 deg, can be used for both girth and longitudinal welds.

Fig. 11 Close-up of welding manipulator with controls

Plate thicknesses up to $^{3}/_{8}$ in. in thickness have been successfully welded with one pass eliminating the necessity for beveling, back chipping and back welding. The weld penetration, controlled by the water-cooled copper backing roller, normally is ground flush with the base metal. Plate thickness beyond $^{3}/_{8}$ to 1 in. are prepared with $^{3}/_{16}$ land and a modified J bevel. The welding head is mounted on a quick operating adjustment mechanism to allow the welding operator to direct the barrel of the machine. This is necessary, particularly on girth welds, since the girth seam may not be perfectly true or round and large vessels have a tendency to "walk" while rotating. In the event the adjustment of the mechanism is insufficient to take

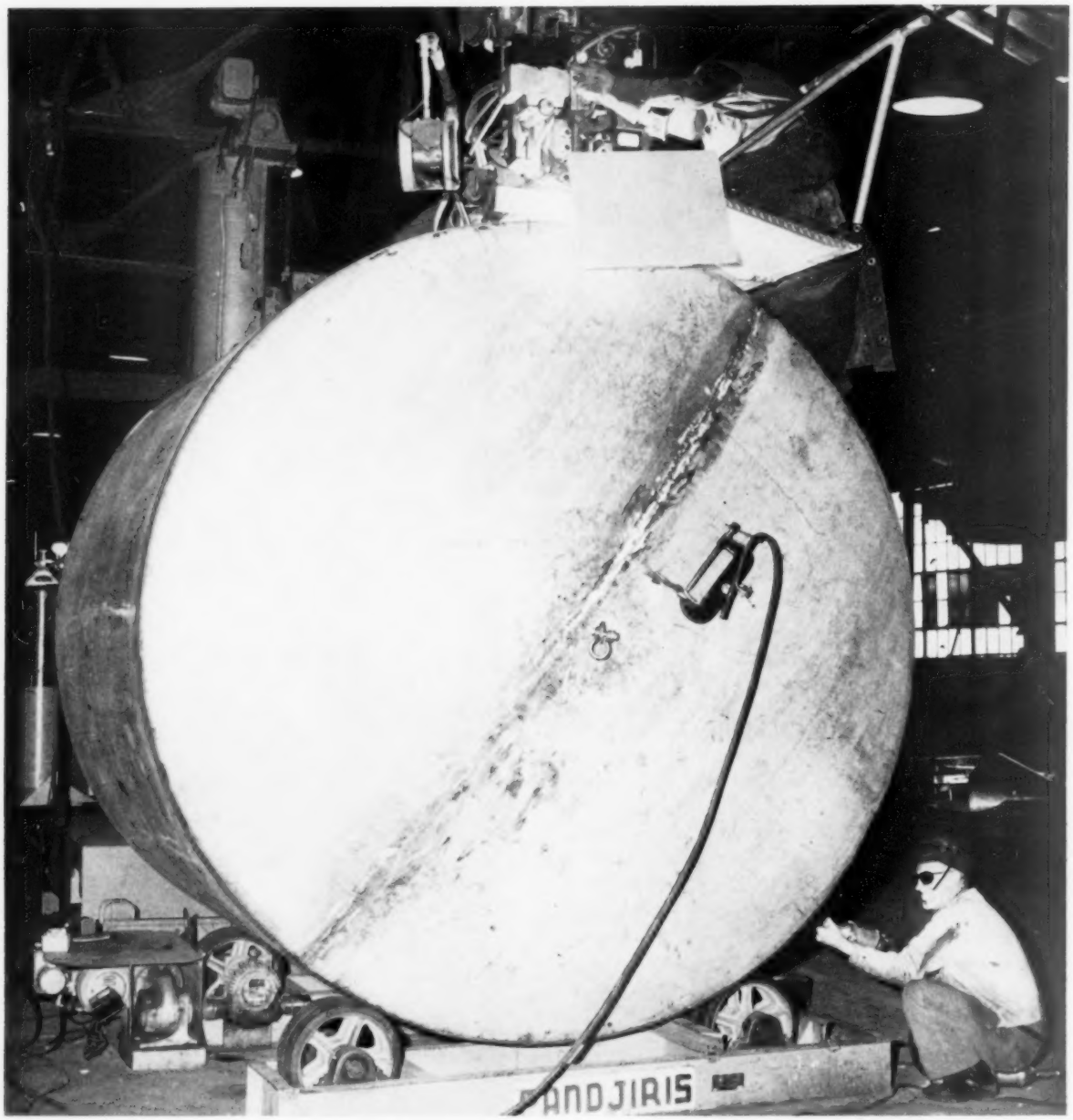

Fig. 12 Automatic welding of girth seam on large-diameter vessel. Worker at lower right is shown cleaning welds

care of these variations, the welding boom can be jogged in either direction. The maximum amount of adjustment is built into the welding equipment to take care of all contingencies.

Inspection

Inspection procedures play an important part toward obtaining high-quality welding results. Checking and inspecting operations during fabrication are necessary to avoid costly repairs and delays. Prior to completion, the following intermediate inspections are made:

(*a*) Layout and Forming—All plate layouts are checked for accuracy prior to cutting and forming. All formed elements are checked for correct shapes and sizes.

(*b*) Assembly—All plate preparations, root openings and fitting openings are inspected prior to welding.

(*c*) Welding—Weld seams are inspected visually, by the liquid penetrant method and by radiography.

(*d*) Final Assembly—Completed vessels are checked dimensionally, for orientation of nozzles and appearance of vessel.

All pressure vessels are subjected to a hydrostatic test in the presence of a representative of an inspection agency. If required, vessels are also subjected to a halogen snifter leak-detector test or a mass-spectrometer leak test. The halogen leak test procedure involves the introduction of a mixture of air and Freon 12 (or equal), at a 10 lb pressure, into the vessel. [Halogen elements (chlorine, fluorine, bromine, iodine) are present in a vast number of chemical compounds. Freon 12 is the halogen compound most frequently recommended.] A probing element is used to pick up any leakage of Freon through the welds and is recorded. The detector operates by sucking a sample of air into a vapor-sensitive element which is assembled into a hand-held probe. The mass spectrometer leak detector test involves the necessity of evacuating the vessel and probing the exterior welds with a helium probe. Any in-leakage of helium is immediately picked up through the mass spectrometer leak detector unit. The leak detector is a simplified portable mass spectrometer sensitive to minute traces of helium. The detection of helium in the presence of other gases is accomplished by a mass spectrometer tube, which ionizes a fraction of all the entering gas molecules, then separates the ions of molecular weight 4 (helium) from all ions of different weight. The helium ions are focused upon a collector by a combination of electric and magnetic fields. The helium ion stream to this collector forms an electric current which is amplified to operate a panel meter and an audible alarm (see Fig. 13).

Conclusion

The application of the various shop procedures outlined are necessary requisites for obtaining consistently high-grade welding performance. The quality of the end product is directly related to the control of all intermediate operations of manufacture. Control of these operations is accomplished by setting minimum standards of acceptance of workmanship which are maintained through shop supervision and inspection. Competent shop supervision is dependent upon complete understanding of the objectives and adequate training in current methods of production. Reduction in manufacturing costs are the result of adapting the use of the latest welding techniques, welding equipment and material-handling equipment including positioners, power turning rolls and manipulators.

In the final analysis, quality welding and workmanship are the result of the implementation and control of specific shop operational procedures by shop management.

Fig. 13 Leak testing of oxygen storage vessel

RECENT DEVELOPMENTS IN MAGNETIC-FORCE WELDING

Magnetic-force equipment is described as having the ability to accurately produce and reproduce certain combinations of heat, time and pressure which are not obtainable with conventional resistance-welding equipment

BY E. J. FUNK

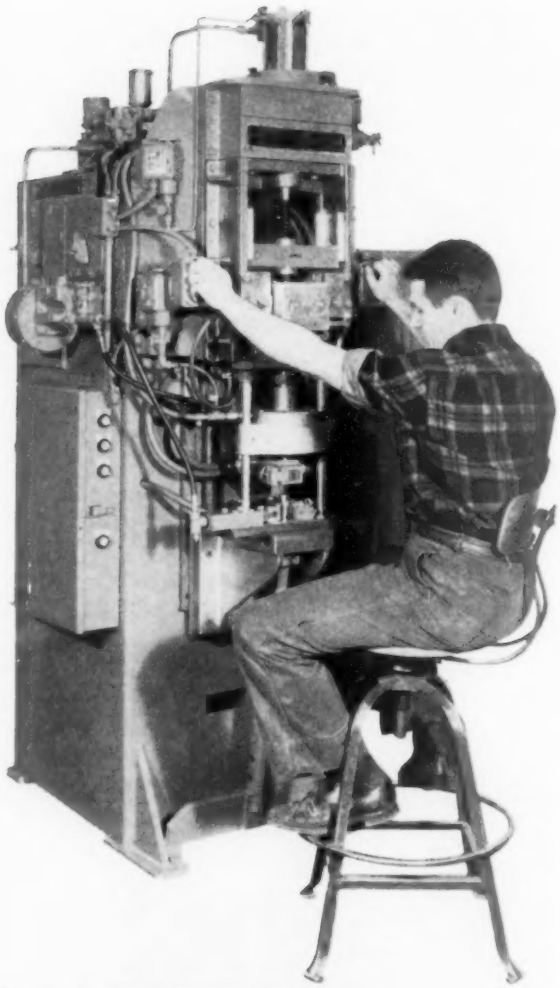

Fig. 1 Magnetic-force welder

INTRODUCTION. Much time and energy has been expended developing the technique of resistance welding and in perfecting resistance-welding machines. One of the most outstanding accomplishments since the advent of electronic timers and contactors has been the development of a device which allows extremely accurate synchronization of the electrode-force application.

Resistance-welder manufacturers are currently being called upon to provide equipment which is capable of handling critical welding applications in materials whose characteristics are unfavorable to the resistance-welding process. Machines intended for these critical applications must be capable of accurately controlling the basic variables of current, time and pressure. Due to mechanical limitations, programmed pneumatic systems are subject to variations which result from inertia, friction, air flow and erratic valving. Since the current magnitude and duration can be very accurately controlled, the most logical solution to the problem of controlling the electrode force is that of making it a dependent function of the welding current. Machines deriving their electrode force from an electromagnet which is interposed in the secondary circuit of the transformer and energized by the welding current have been under development since 1946. Many of today's difficult welding problems have been satisfactorily solved by being subjected to a welding technique wherein the electrode force is inherently synchronized with current magnitude and duration.

This report is intended to make available the results of recent progress by presenting data pertaining to the characteristics of machines of present design, and describing the methods of controlling electrode-force application. It also describes a new type of welding process which has extended the field of usefulness of magnetic equipment and of resistance welding as a whole.

Design Principles. The magnetic-force welder is fundamentally a conventional direct-acting ram-type spot welder which has undergone design changes to accommodate an electromagnet for application of electrode pressure. Figure 2 is a skeleton schematic of the electrical and physical arrangement used in present-day single-phase equipment. The current flow is controlled by a conventional electronic timer and sequence control, and passes into the primary of the welding transformer which is of a special design, having components sized in such a manner as to meet the requirements of magnetic-force welding. The secondary current is directed to the split-iron-core magnet and makes one turn around the stator, after which it passes through a flexible laminated roll lead to the upper electrode holder. The return path is completed after the current passes through the weldments and lower electrode.

A small air cylinder is provided to lift the electrode to the desired opening for work insertion and removal, and to provide clamping pressure. The ram is of the quill type being rigidly supported by linear action ball bushings which allow extremely fast follow-up with a minimum of mechanical friction. The center portion of the ram is threaded to allow adjustment of the force collar which supports the magnet armature; the effect of this adjustment is discussed elsewhere in this report. The lower end of the ram is securely attached to the upper electrode holder which is usually of an ejector type, designed for number two Morse-taper tips. The lower knee is a high-conductivity copper casting which is provided with a tee-slotted platen for universal die mounting and supported by means of the face-plate and an adjustable knee-jack.

Machine Characteristics

The behavior of the force in a magnetic welder is con-

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trolled by the same physical laws that govern the behavior of any electromagnet. These laws state that in a magnetic circuit, the flux is directly proportional to the impressed magnetomotive force, and inversely proportional to the reluctance of the magnetic circuit. Since it is the force magnitude with which we are concerned, it will facilitate the following discussion, if we recognize that the force is a direct result of the flux in the armature and, therefore, synonymous with it. The magnetomotive force of the circuit is proportional to the strength of the current in the conductor and to the number of times the current encircles the magnetic path, and usually is expressed in terms of the product of amperes and turns, or ampere-turns. Since the welding-current conductor has only one turn around the core, the magnetomotive force may be considered a direct function of current magnitude. The reluctance of a magnetic circuit is proportional to the length of the circuit, inversely proportional to the cross-sectional area, and depends upon the magnetic properties of the materials composing the circuit. Magnetic-force welders are designed so that the air gap between the armature and the stator of the magnet may be adjusted in order to allow variation of the reluctance of the magnetic circuit. We may conclude from theory that the magnetic force is directly proportional to current and inversely related to the air gap.

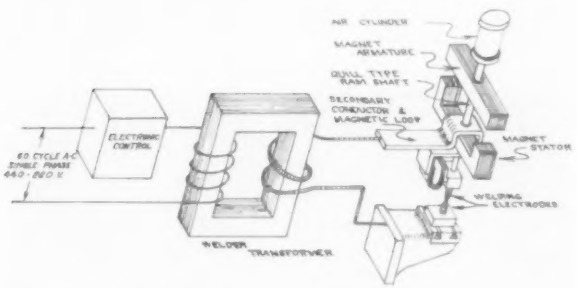

Fig. 2 Skeleton schematic of a magnetic-force welder

The Effect of Current

Figure 3 shows a set of experimental curves obtained from a study of the force characteristics exhibited by a 75-kva welder. In this case, the maximum force is plotted as a function of welding current for several magnetic gaps. The reader will observe that the actual performance is in good agreement with the theory described in the preceding paragraph; that is, magnetic force has a linear relation to current and is reduced by an increase in gap.

Information of this type is useful during set-up procedures as it gives the operator an indication of how his adjustments effect the welding conditions. Recalling that the rate of heat generation in a resistance-welding situation is proportional to the product of the resistance of the welding circuit and the square of the current, it can be seen that adjustment of transformer taps or phase shift settings, in such a manner as to increase the current magnitude, would have the following effect on the welding situation: first, the rate of heat generation would increase as the square of the increase in current magnitude; and, second, the electrode force would increase which would reduce the electrical contact resistance and at the same time better the conditions for heat transfer away from the work. Both of these effects would cause a reduction in the apparent heat present at the weld zone. Experience has shown that the decrease in heat, due to the increase in force which accompanies a current increase, is small with respect to the increase in heating caused by the additional current and, for the most part, need not be considered during set-up procedures.

The Effect of Magnetic Gap

The effect of magnetic gap may be observed in Fig. 4, which shows maximum force plotted as a function of gap for several transformer taps. The curves were plotted from the same data that were used for the previous set of curves, which depicted force as a function of current, and are intended to show the reader the manner in which force varies when all machine settings remain constant with the only variable being magnetic

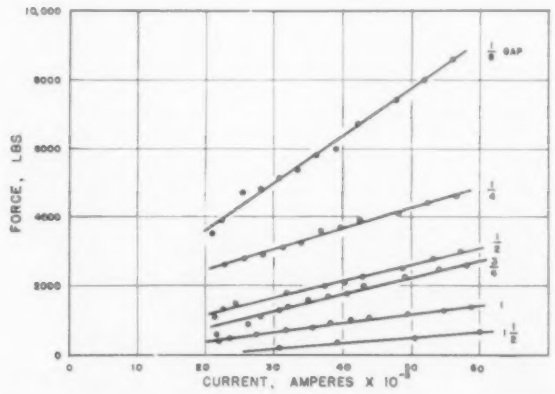

Fig. 3 The effect of current on magnetic force at various magnetic-gap settings

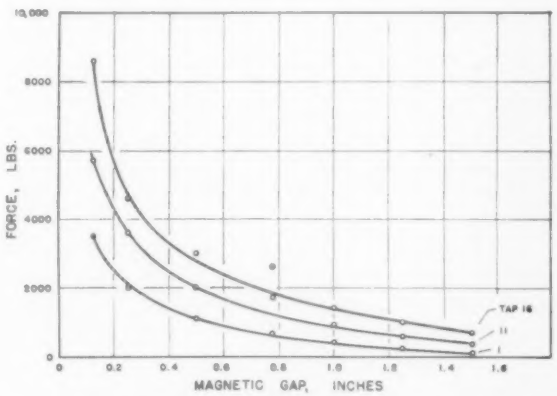

Fig. 4 The effect of magnetic gap on force magnitude for several transformer taps with other control settings remaining constant

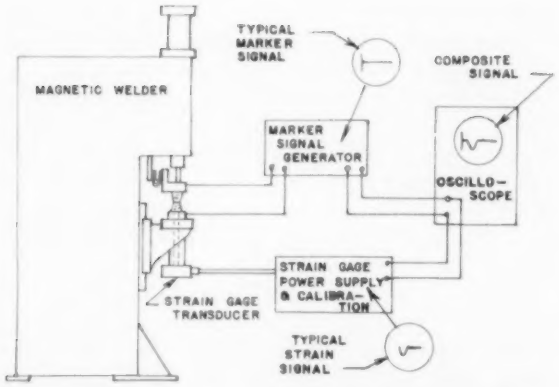

Fig. 5 Block diagram of the instrumentation setup used to study the effect of delayed forge

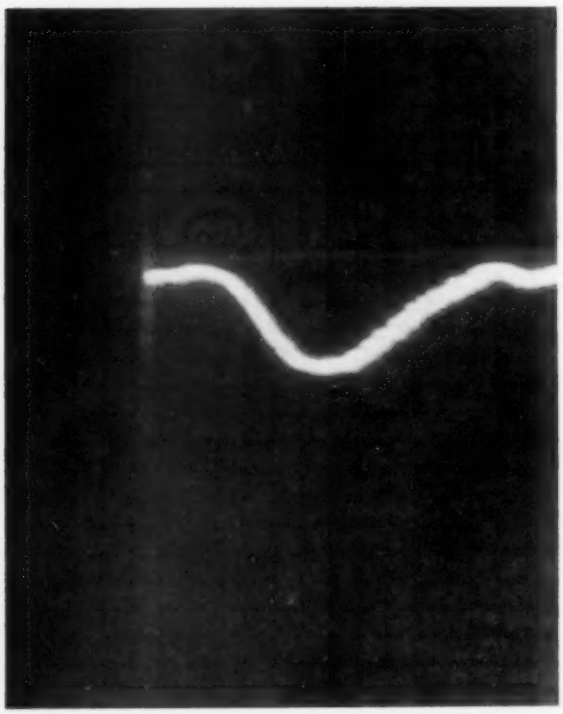

Fig. 6 Oscillogram of a normal magnetic-force pattern

gap. It is interesting to note that the experimental results indicate that the forces tend to respond in accordance with Coulomb's law for point poles which states, in part, that the force of attraction is inversely proportional to the square of the distance between poles.

This information is useful from a standpoint of operating the equipment because it shows that small adjustments of magnetic gap in the range of $^1/_8$ in. will produce large differences in the force; whereas, much larger adjustments in the range of 1-in. gap opening will result in practically no change in force.

Magnetic gap opening has one effect which is not readily observed in the curves shown in Figs. 4 and 5; that is, the slight increase in secondary current which accompanies an increase in gap. It was observed, for example, that the current increased from 56,000 to 60,000 amp during the course of the investigation at the top transformer tap, as the gap was changed from $^1/_8$ to $1^1/_2$ in. The relative magnitude of the increase is of no practical importance in so far as operation is concerned and its notation is included here simply to make this a more complete discussion of machine characteristics.

Delayed Forge

The early approaches to the development of magnetic equipment involved the use of rectified three-phase welding current which yielded a force with a wave form having considerable ripple and a continuous force application throughout the heating cycle. The development of single-phase equipment was delayed because early experience led the experimenters to believe that the relaxation of magnetic force, which occurred as the current wave changed polarity, would have an unsatisfactory effect on the weld. However, in the course of experimental welding, it was found that the required heating times could be very short, often only one-half cycle, and the development trend turned to single-phase equipment. At this point, it was found that welding schedules having these extremely short heating periods required some rather high values of current as compared with conventional spot-welding applications. The original single-phase machines were ultimately called upon to perform welding tasks for which they simply did not have enough capacity. It was out of the need to extend the capacity of small

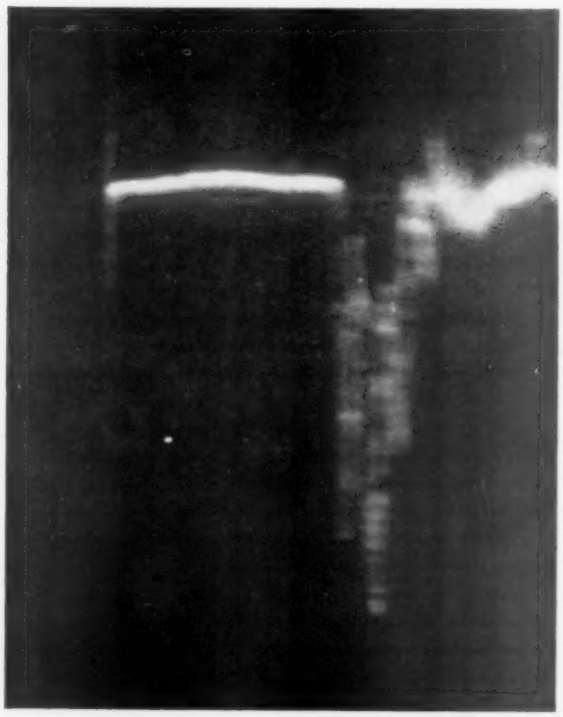

Fig. 7 Oscillogram of a magnetic-force pattern resulting from the use of delayed forge

machines and enable them to encompass a greater range of work that an idea for controlling the time of application of magnetic force was evolved. It was thought that if a period of heating time was allowed to take place before the electrode pressure, due to magnetic action, was applied, a lower current would be needed to accomplish the same amount of heating and thereby the power requirements of the machine reduced.

The principle is simple; it involves the use of a delay magnet, energized from a direct-current source, which withholds the application of electrode force until the force due to the welding current becomes of sufficient magnitude to pull the armature away from the holding poles. In the actual design the delay magnet has a break-away strength of something on the order of 50 lb and serves to hold the armature a small distance above the collar on the welding ram. As the welding current builds up, the holding force is rapidly overcome and the armature is accelerated for a short distance before coming in contact with the ram. The amount of free travel, experienced by the armature from the time it leaves the delay magnet until the time it bottoms on the ram collar, is known as the "delayed-forge gap." The delayed-forge gap should not be confused with the basic magnetic gap which is determined by the position of the ram collar, with the work in place, and refers to the distance between the armature and the stator poles. The two quantities are independently variable although it will be shown that the resulting force wave is a function of both.

Instrumentation

A laboratory investigation has been conducted to determine the effect of the delayed-forge system on the resulting electrode pressure wave with respect to time and magnitude. Figure 5 shows a block diagram of the instrumentation setup used for that study. In order to establish the time relationship, a marker signal was used to trigger the sweep of a cathode-ray oscilloscope. The oscilloscope was, in turn, used to record the force wave from a potentiometric strain-gage circuit. The marker signal was produced by a thyratron circuit which was initiated by means of the voltage drop across the welding electrodes. The purpose of the marker signal was twofold: first, to trigger the sweep of the scope as the strain gage signal was of insufficient magnitude to do so; and, second, to provide a reference point from which the time relationship of the various force patterns could be determined.

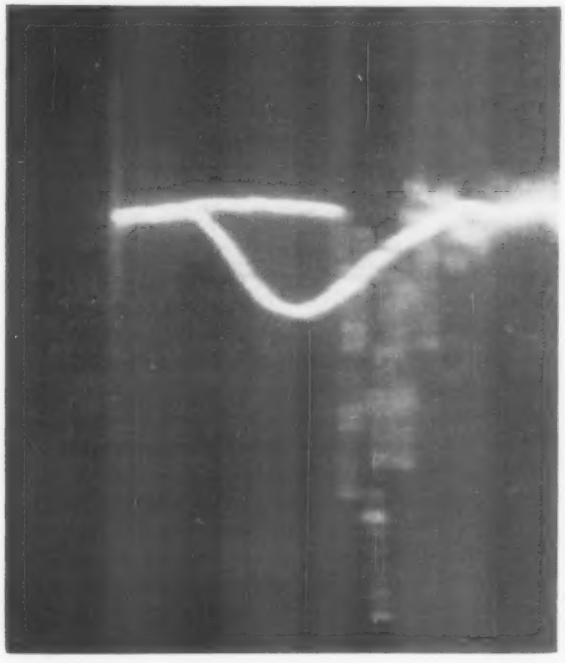

Fig. 8 Oscillogram allowing comparison of magnetic-force pattern obtained with and without delayed forge

The Effect of Delayed-Forge Gap

Figure 6 is an oscillogram of the force wave which results from normal magnetic welding conditions without the use of the delayed-forge system. The gradual increase from zero to a maximum and back to zero follows the current wave and is typical of a half-cycle welding situation. Figure 7 shows the force trace which results from using the same magnetic gap and control settings as those of Fig. 6, except that in this case the delayed-forge system was in operation with a $^{3}/_{8}$-in. delayed-forge gap. The resulting wave form is considerably different in that instead of a gradual increase and decrease of force, there is an almost instantaneous build-up of magnetic force that is followed by a number of transients which decay at a higher rate than the normal force wave.

Figure 8 is presented in order to give the reader a clear understanding of the relationship of the two force systems. In it the two wave forms of Figs. 6 and 7 are superimposed by means of a double exposure and they may be compared with respect to both time and amplitude. As was explained earlier, their time relationship is established by means of the time-marker signal, at the extreme left of the figure, which was employed to initiate the horizontal sweep of the oscilloscope. Study of this data will reveal that the delayed-forge system allows a long heating period to occur during which the weldments are subjected only to the clamping force provided by the air cylinder. The heating period is terminated by the impact force wave which completes the weld cycle. It may also be observed that the magnitude of the two force waves is quite different depending on the force system employed. The higher values, which result from the use of the delayed-forge system, are due to the energy storage which occurs as the magnet armature traverses the delayed-forge gap.

Figure 9 is a graphical tabulation of data concerning the effect of various delayed-forge gap settings on the time and magnitude of the resulting force wave. The peak force is plotted as a percentage of the maximum value of force obtained without delayed forge (Fig. 6). Delay time is plotted in units of electrical degrees* and

* 360 deg per cycle at 60 cps.

represents the time difference between the points of force initiation under normal magnetic welding conditions and under delayed-forge conditions. Examination of the curves reveals that increasing the delayed-forge gap results in a corresponding increase of delay time. However, an increase in gap does not necessarily dictate a corresponding increase in force magnitude. It can be seen that a point of diminishing return is reached after which an increase in delayed-forge gap yields a decrease in force amplitude.

It has been found in practice that the delayed-forge system accomplishes its original purpose of reducing the power requirements for certain applications and the feature is included in present-day designs. The system offers an additional advantage which is a direct result of the increased force magnitude. In the welding of electrical contacts, one often encounters the highly objectionable condition of clearance existing between the contact and its arm after welding. The problem of obtaining complete setdown has been satisfactorily solved in a number of production cases through the use of delayed forge.

Magna-Flash Welding

As a result of the need to weld over the entire area in the manufacture of the electrical contact shown in Fig. 10, the usefulness of magnetic-force equipment has been widened to include a long list of possible applications. The weld shown in Fig. 10 was accomplished by means of a process which has come to be known as "magna-flash welding." Essentially, the process involves the use of a small projection which is caused to disintegrate and assist in the formation of an electric arc at the interface of the weldments. Once the arcing has occurred, the weldments are brought into intimate contact and allowed to cool. The final joint is welded over its entire area and exhibits very fine electrical and physical characteristics. Interest created by the success of the electrical contact assembly stimulated a development program aimed at applying the magna-flash technique to the manufacture of automotive valve lifters. The problem, in this case was that of joining the cast-iron foot, which rides against the engine camshaft, to a mild-steel tube or body. Figure 11 shows three configurations which have been successfully welded by the magna-flash method. Two of the lifters shown have been sectioned through the welded end in order to reveal internal details. The lifter on the extreme left is made up from a mild-steel tube which has been cut to length and welded to a cast-iron disk. The combination, shown second from the left, consists of a cast-iron disk welded to an extruded-steel body and is characterized by the closed end of the extrusion which produces a void beneath the disk. Both of the preceding types of lifters discussed are similar in that they have annular type joints produced by means of a ring-type magna-flash projection. The configuration shown on the extreme right represents a disk-type joint and was produced by means of one centrally located magna-flash projection.

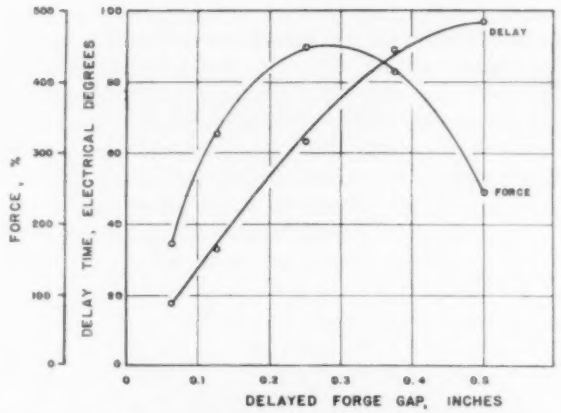

Fig. 9 The effect of delayed-forge gap on relative force magnitude and delay interval

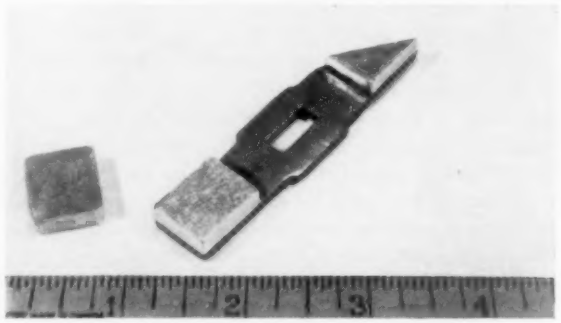

Fig. 10 Electrical contact assembly welded by the magna-flash process

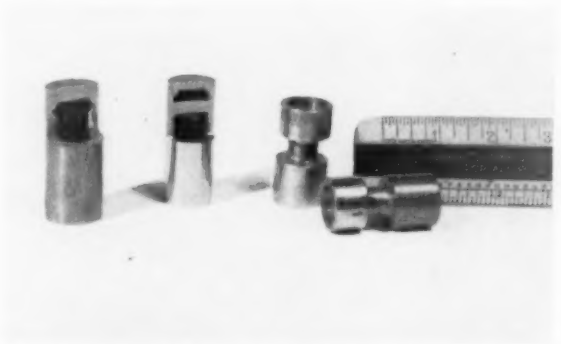

Fig. 11 Automotive valve lifters welded by the magna-flash process

Figure 12 shows a photomicrograph of a typical valve-lifter joint at a magnification of × 500. The upper portion of the micrograph shows the unaffected cast iron which consists of graphite flakes and carbides, dispersed in a matrix of fine to semicoarse lamellar pearlite. Progressing downward, a heat-affected zone can be observed in the cast iron which consists of 10% eutectic ledeburite and is about 0.003 in. thick. The diffusion zone is martensite layer and varies in thickness from almost nil to 0.001 in. and is adjoined by a heat-affected zone in the steel body identifiable by patches of

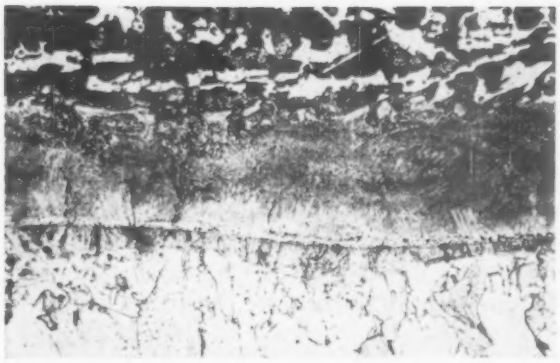

Fig. 12 Photomicrograph of a magna-flash weld in an automotive valve lifter. X500 (Reduced by $^1/_2$ upon reproduction)

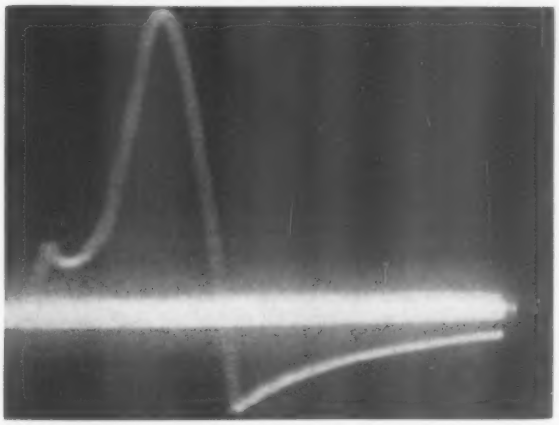

Fig. 13 Typical oscillogram of the current trace encountered in magna-flash welding

martensite and blocky ferrite. The unaffected structure of the valve-lifter body is that of a 1010 steel with fine lamellar pearlite existing in a ferrite matrix.

The narrow nature of the entire heat-affected area is typical of magna-flash welds in general and gives some indication that the welding process involves an intense heating over an extremely short period of time. In the case of the valve lifters, it is essential that the heating, due to welding, be confined to a small area in order to preserve the properties of the cast iron. It can be seen from the micrograph that this requirement is easily met by magna-flash welding.

Principles of Magna-Flash

Understanding the magna-flash process requires consideration of a different set of variables than are normally thought of in connection with resistance welding. Of course, the primary fundamentals of current, pressure and time are still just as important to magna-flash as they are to other resistance-welding processes, but the author has found it convenient to think in terms of electric arcs, and fast follow-up, rather than of a heating process which depends upon the

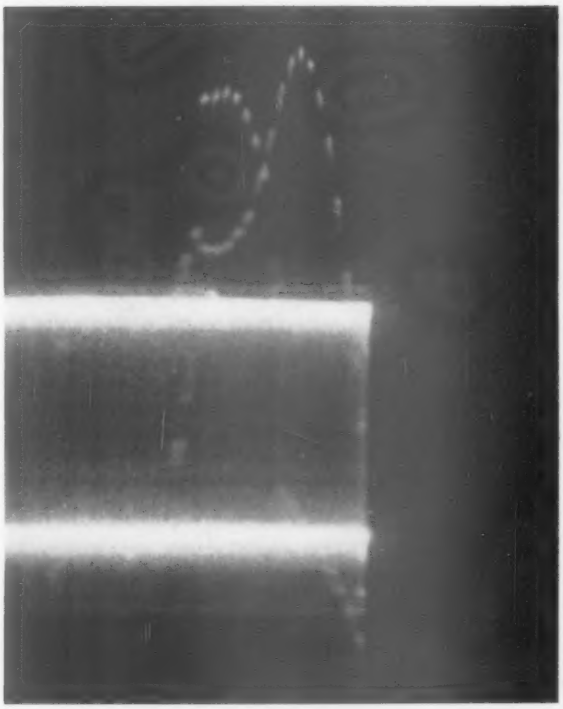

Fig. 14 Oscillogram allowing comparison of current and voltage variation in magna-flash welding

flow of an electric current through resistance of the welding circuit.

The primary current wave associated with a magna-flash weld is shown in Fig. 13. Examination of this oscillogram reveals a peculiar decrease in current that occurs soon after the initial current flow starts. The momentary decrease is soon followed by a new increase which continues to a maximum and then drops off as would be expected of a sine wave. Since the wave form shown resulted from a half-cycle weld time, the initial current pulse is followed by a surge of current in the opposite direction which is induced by the collapsing transformer field and gradually decays to zero. The observation of the unusual "notch-effect," occurring in the leading portion of the current wave, resulted in further investigation of the current and voltage relationships involved in the magna-flash process. The curves shown in Fig. 14 were obtained through the use of an electronic switch in conjunction with an oscilloscope and show the relationship which exists between current and the voltage drop across the weldments. The upper base line represents the zero position for current and the lower base line is the zero reference for voltage. Recalling the shape of the current wave from Fig. 13, it is possible to identify the voltage curve. Study of the voltage variation, with respect to current, will reveal that there is an instantaneous increase in voltage which becomes stabilized and remains nearly constant throughout the duration of the "notch effect," observed in the current wave. The voltage

experiences a very rapid decrease almost simultaneously with the second increase in current.

The behavior of voltage and current is explained in the following manner. At the outset of welding, the two parts are separated by means of a small projection. When the initial flow of current occurs, this projection is heated so rapidly that it disintegrates and assists in establishing an electric arc between the weldments. As the arc is established, the rate of rise of current is interrupted and the current flow is controlled by the arcing conditions. During this period, the voltage first approaches the open-circuit voltage of the transformer and then stabilizes at a value which depends, to some degree, on the materials being welded. As the parts being welded are brought into contact with each other, the arc is extinguished and resistance to the flow of current approaches short-circuit conditions. The voltage across the weldments drops off and is accompanied by a sharp rise in current. Theoretically, the heating is complete when the arc is extinguished, which is indicated by the decrease in voltage, and all that remains to be done, in order to complete the weld, is cooling of the parts under light clamping pressure.

It is interesting to note that the time interval from the initial heating of the projection until the voltage drop occurs, which indicates the completion of arcing, is on the order of 0.0032 sec. The mechanical action of the welder must be capable of bringing the weldments into contact within that period of time in order to effect a successful weld. The ability of the welder components to remain in contact with the work and apply pressure throughout the welding cycle is usually referred to as "follow-up action." Follow-up action in a magnetic welder can be controlled, to a great extent, by adjustment of the magnetic gap.

In practice, it has been found that the tooling for magna-flash welding must be capable of firmly gripping the weldments in order to prevent surface burning which would result from a loss in contact pressure between the weldments and the electrodes. The best results have been obtained with tooling designed so as to depend upon action of the magnetic ram for follow-up and provide an independent source of clamping force which would assure that the weldments remain undisturbed until cooling is completed. Figure 1, shows a 150-kva magnetic-force welder which has been equipped with magna-flash tooling for production of welded valve-lifter units.

Summary and Conclusion

A close examination of the behavior of magnetic-force equipment will reveal that its principal feature is the ability to accurately produce and reproduce certain combinations of heat, time and pressure which are not obtainable with conventional resistance-welding equipment. These combinations of variables have been successfully applied in a number of production situations and are credited with accomplishing the following things:

1. Producing greater weld consistency.
2. Greatly improving electrode life.
3. Joining materials previously considered unsuitable for resistance welding.

As a result of the foregoing accomplishments, the field of resistance welding has been further extended as a metal-joining method which offers reduction of production costs and product improvement. The exact functioning of magnetic welders to bring about the solution of many difficult welding problems is not clearly understood; many facets of the field of magnetic-force technology remain to be explored and explained. However, the time-proved method for improving any process is through continued research and development; and the future will, no doubt, bring about increased understanding and application of the process.

Who's Who?

The Who's Who in Welding read* THE WELDING JOURNAL. *The Journal is required reading for more than 49,800 potential buyers . . . key men in their respective fields . . . representing the largest concentration of purchasing power in the metal fabricating world.*

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DESIGN, FABRICATION AND ERECTION PRACTICES FOR EFFICIENT WELDED HIGHWAY BRIDGES

Service road over Hoover Dam Reservoir Project, City of Columbus, Ohio; eight 85-ft 3-in. spans of 100% welded haunched plate girders with a 24-ft wide roadway and two 1-ft 6-in. safety curbs

Author presents a summary of current practices in design, fabrication and erection through which various states have achieved substantial savings in material and time

BY OMER BLODGETT

Introduction

The experience of a number of states during the past ten years with welded bridges has proved that a savings in steel of 25% over riveted construction can be readily attained. Because of the critical steel situation which the 41,000-mile interstate highway system with its 300,000 bridges and structures will create, the savings in steel that could be realized, if welded design were used, is of important significance to the success of our national program.

This paper presents a summary of current practices in design, fabrication and erection through which various states have achieved these savings in material and time. The information has been obtained through correspondence with bridge departments and through bridge seminars conducted at the Cleveland plant of The Lincoln Electric Co.

Initially a survey was conducted through correspondence with all of the state highway departments, to determine the extent to which welding is being used. Following is a summary of the information supplied by engineers and other personnel of the 46 highway departments responding. The figures are not intended to be precisely accurate, but they do give a broad picture of the extent to which welding is being used.

In the original questionnaire sent to the 48 state highway departments, we asked to know the extent welding was being used in the following four groups of bridges:

1. Use of welding for secondary members, such as bracing, bearings, expansion devices, shear attachments, etc.
2. Use of welding for cover plates on wide flange beams.
3. Use of welding for the fabrication of plate girders.
4. Use of welding for field splices of girders.

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Presented at the 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8-12.

Of the 46 states responding to the survey, all used welding on secondary members, 35 or 76% made use of welded cover plates, and 22 or 48% were using an increasing number of welded plate girders for their highway bridges.

A survey, made by the Subcommittee on Welded Bridges of the American Association of State Highway Officials in 1950, showed that, at that time only six years ago, only ten states reported using all-welded construction.

Arkansas has its first all-welded plate girder bridge, four lines of girders. Three spans are wide flange beams and eight spans are welded plate girders, 75 ft, five at 120 ft, 123 ft. Four additional bridges with welded plate girders have been placed under contract.

California is famous for its welded San Francisco Freeway made up of about 30,000 tons of welded steel which would be equivalent to 9½ miles of two-lane highway. In addition to this, there are about 70 completely welded bridges under traffic.

Colorado has some welded bridges on the Denver-Boulder Turnpike.

Connecticut has, at last count, 29 all-welded bridges and about 21 partially welded bridges.

Florida has, from time to time, used many welded bridges of various types on their State Road System. Practically all of their I-beam spans are constructed with welded cover plates on the bottom flange and composite construction at the top flange provided by means of welded shear developers. They also have the following welded plate girder bridges:

5 movable span bridges.
3 continuous three span bridges, 84 ft, 126 ft, 84 ft.
1 continuous two span bridge, 150 ft, 150 ft.
1 continuous bridge with two units of three spans, 123 ft, 154 ft, 123 ft.
1 through girder span of 110 ft.

In addition they have several other large plate girder spans for prospective design.

Georgia recently built its first all-welded plate girder bridge using four lines of girders. Four spans are wide flange beams and four spans are welded plate girders, 116 ft, 154 ft, 154 ft, 116 ft.

Illinois has designed and constructed its first all-welded steel plate girder bridge, a three-span continuous bridge, 140 ft, 179 ft, 140 ft. There are ten lines of girders. The state has used welded cover plates for the past 20 years.

Iowa has used welded cover plates for many years. They have four welded plate girders already constructed, four more under contract and six scheduled for early letting.

Kansas built their first all-welded bridge, a four-span continuous girder bridge, in 1949. At the present time, their State Highway System has 16 all-welded plate girder bridges with a total length of 7787 ft. They also have 133 bridges with a total length of 41,978 ft of a continuous wide flange beam construction having welded cover plates and welded bearing devices. During this time, the counties in Kansas have constructed 156 continuous I-beam bridges with welded cover plates and ten welded plate girder bridges. There are a total of 254 welded bridges on the Kansas Turnpike made up of the following:

28 bridges—100% welded, flange to web, field splices and bracing.
8 bridges—wide flange beams with welded splices.
218 bridges—wide flange beams with welded cover plates, stiffeners, with riveted or bolted field splices.

Kentucky is designing its first all-welded plate girder.

Louisiana has an all-welded plate girder bridge using A242 steel. The New Orleans Terminal Project made extensive use of welding on their overpass.

Nebraska constructed their first all-welded plate girder bridge in 1953. Since that time, they have ten of these completed or under contract and six or more on the drafting table.

New York has erected nearly 800 welded steel bridges since 1942. Practically all of the 500 bridges on the New York State Thruway are welded. They also have a welded railroad bridge over the Cherry Valley Turnpike.

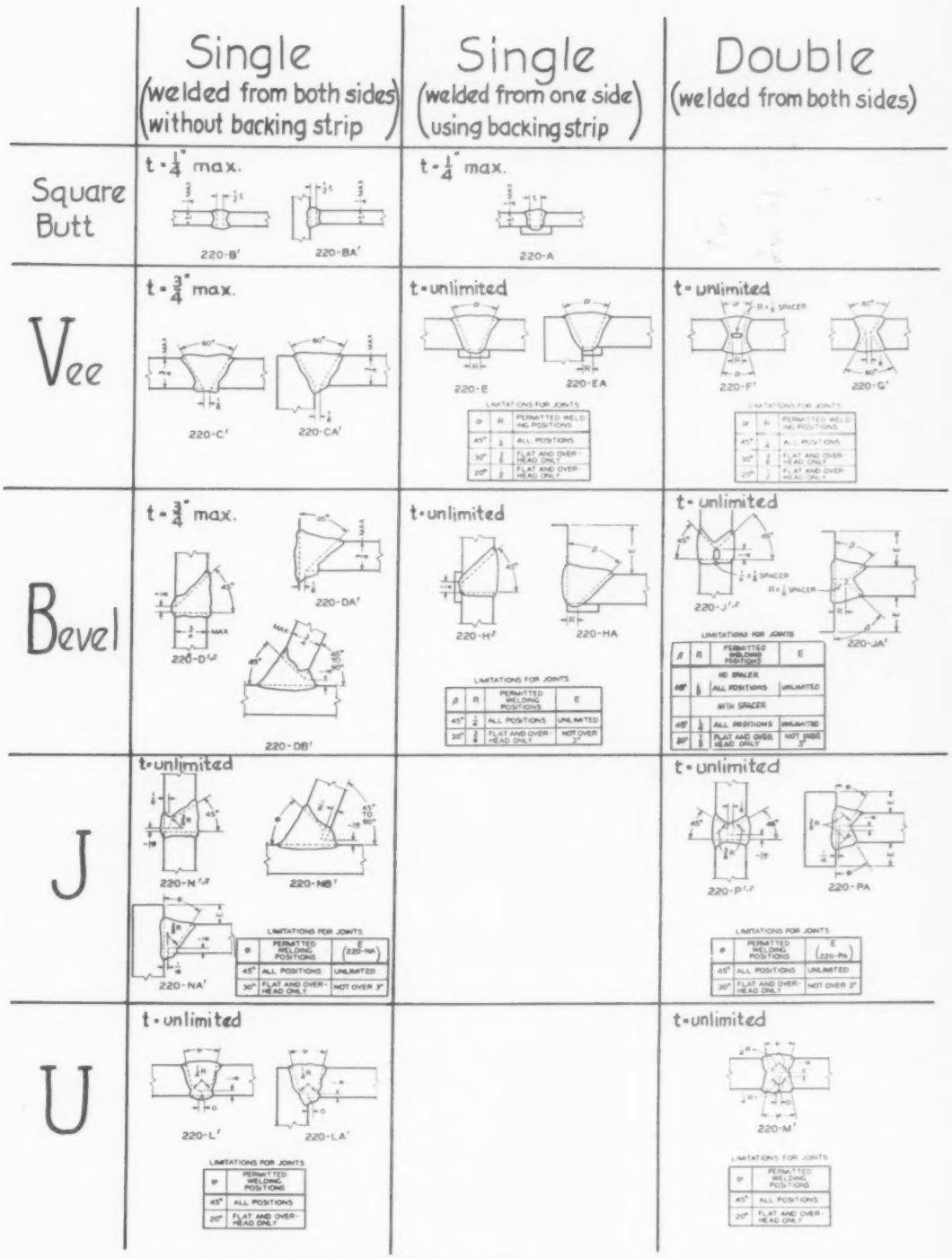
Ohio, for the past 20 years, has designed and built approximately 500 continuous steel beam bridges of three or more spans each, with welded splices over the piers, cover plates, welded bracing, railings, expansion devices, etc. Three pedestrian overpasses, of the all-welded thru-arch type, have also been constructed, the largest having a span of 205 ft. Recently an all-welded continuous girder bridge was placed under contract. This structure has end spans of 90 ft and four interior spans of 112.5 ft each. Two additional welded girder bridges now are being designed, one with interior spans of 246.5 ft.

Oklahoma has under construction six welded continuous plate girder bridges with 47-, 94-, 47-ft spans and two welded girder bridges with 54-, 108-ft, 54-ft spans. Plans are completed for ten more of these bridges and for two double continuous plate girder bridges, 109-, 142-ft spans.

Oregon has constructed six welded plate girder bridges ranging from 40-ft simple spans to a continuous series, 90 ft, 160 ft, 90 ft.

South Dakota has, for the past ten years, considered welding the conventional method for making structural connections on all of their bridges with the exception of truss spans.

Texas currently designs nearly every steel bridge with span lengths less than 160 ft for welded fabrication with the field connections also welded. The designs are generally continuous deck structures involving one or two field splices in line of beams or girders. For span lengths under 90 ft, the stringers are wide flange beams; for longer spans, they are plate girders. They have, under contract, plate girder design bridges with span lengths up to 270 ft wherein the girders are



1. Gouge root before welding second side
2. For horizontal joints only

Fig. 1 Joints prequalified by the American Welding Society for use on welded bridges

fabricated by welding, but the field splices in the girders are to be either riveted or bolted. The connections of the sway bracing and laterals will be provided with holes to aid in erection, but the field connections will be welded. Their Highway Department has done an outstanding job in setting up procedures for the erection of its bridges. This information has been printed in a manual titled "Construction Inspection of Welded Steel Bridges." They are also doing a fine job of instructing their own men by means of clinics which they have set up.

In addition, the following states also have designed

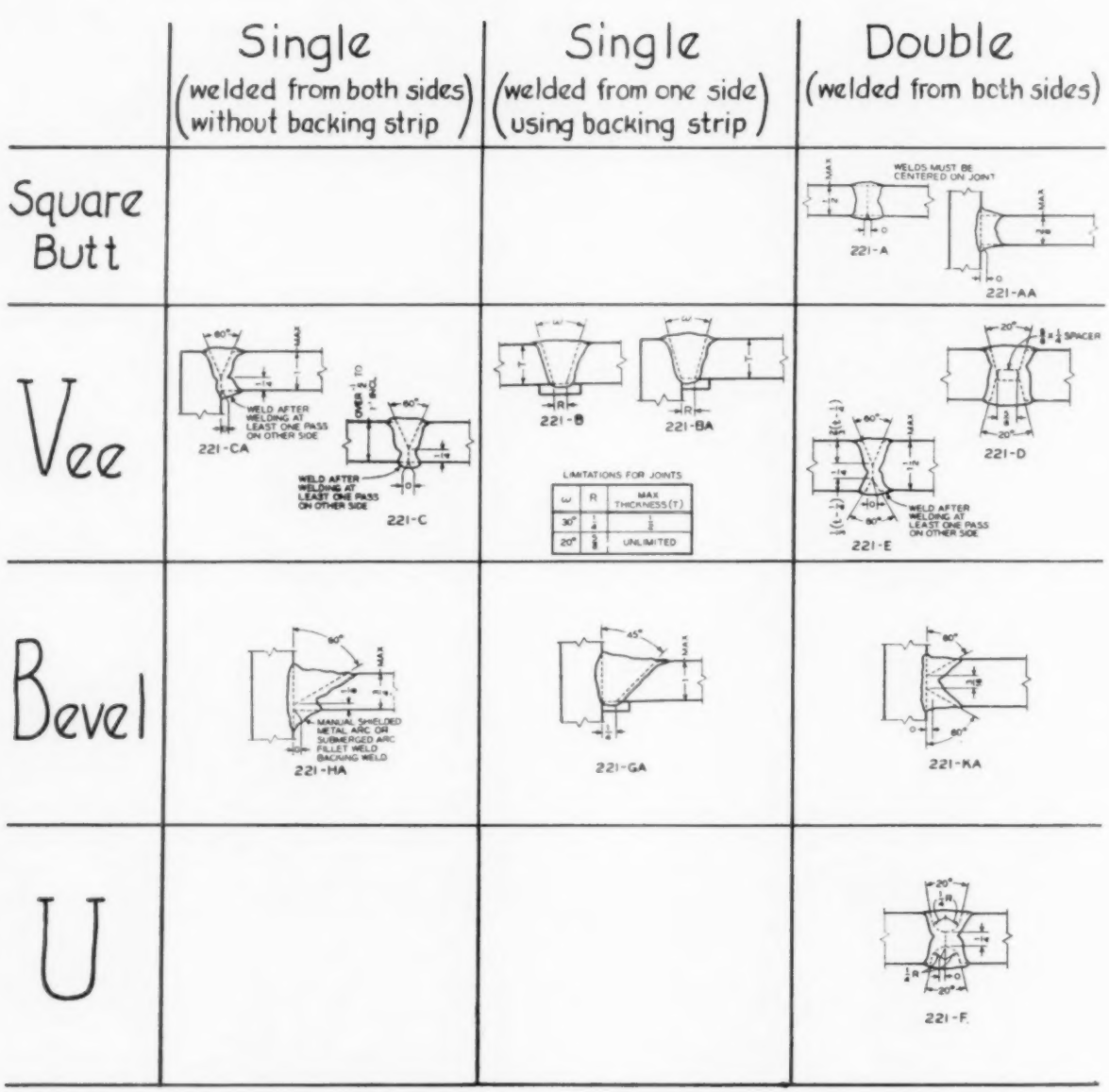


Fig. 2 AWS prequalified joints for use with the submerged-arc welding process

or are designing welded plate girder bridges: Massachusetts, New Hampshire, North Dakota, Rhode Island, Vermont and Wyoming.

The impetus to welded design for highway bridges developed with the change from the through-type to deck-type bridges. This latter type, incorporating composite construction, supplied safety, functional appearance and economy through welded design. Using the full section of steel members provides for efficient and economical use of material, since no reductions are necessary as with riveted structures.

In many cases, especially where continuous design is used, the over-all depth of the bridge deck can be reduced significantly. This not only provides for necessary headroom under the bridge, but effects appreciable savings. Of equal importance are the savings in the foundation and fills. Saving 1 ft in depth at the bottom of the usual fill, when extended on the bridge approaches which constitute miles of highway, can mount to major proportion in saving money.

Standard Joints

American Welding Society approved joints are not used by all of the state highway departments. Apparently some states are not aware of the standard joints as set up by the American Welding Society and have set up their own joint details. The use of approved joints should be a 100% practice, since it is more economical to use prequalified American Welding Society joints. These joints are good and sound, and the standards cover practically every type of joint required. In order to aid in the use of these

prequalified joints, they have been rearranged and put on a single chart, Fig. 1.

The AMERICAN WELDING SOCIETY uses the following types of joints: vee, bevel, J and U. Along with this, they recognize two types of joints, the single joint and the double joint. The AMERICAN WELDING SOCIETY'S Bridge Code specifies that all strength butt welds must have 100% fusion. On single welds, this may be done by root chipping the back of the joint and welding a backpass, or the joint might make use of a backing strap. Wherever a vacancy occurs in this chart, it simply means that the particular joint is not a prequalified AMERICAN WELDING SOCIETY joint.

A similar chart, Fig. 2, has been made for the prequalified joints made by the submerged-arc automatic welding process. On both of these charts, the complete data necessary for the joint are included.

Floor Construction

Accompanying illustrations show typical floor construction as used in recent welded highway bridges. The floor in Fig. 3 (*a*) makes use of diagonal beams to obtain additional torsional resistance. This particular example was taken from the welded arch bridge over the Rio Blanco River in Mexico and could be used on the standard plate girder bridge. Although there is a little extra fabricating time required in this, it does increase the torsional and lateral stability of the floor system tremendously. The bridge in Fig. 3 (*b*) is made of two longitudinal girders with floor beams attached to the girder. The floor is made a part of the structure through spiral shear attachments. The bridge in Fig. 3 (*c*), made of two box girders, was constructed in Washington. One of its advantages is extra torsional resistance obtained through the closed box section. Figure 3 (*d*) represents a typical bridge made up of two longitudinal girders with floor beams attached to the webs and stiffened through brackets. The longitudinal stringers are continuous and are attached to the floor beams. Additional work could be done in regard to the connection between the stringers and the floor beams, so that proper continuity may be obtained without too much difficulty in making the joint.

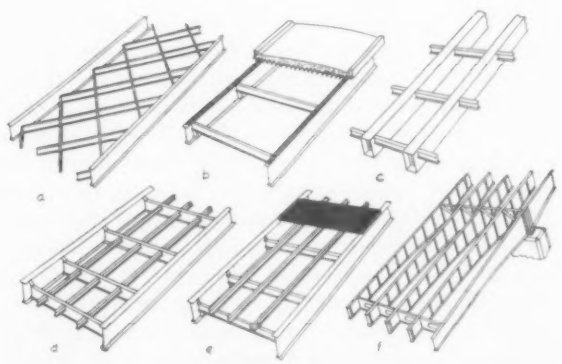


Fig. 3 Typical bridge floor construction used in recently built welded highway bridges

In the bridge shown in Fig. 3 (*e*), the continuous stringers are placed on top of the floor beams. This gives a level surface with the top flange of the longitudinal girder, so that an open steel grid floor can be placed all the way across the top surface. It is a simple matter to field weld the stringers to the floor beams through the use of downhand fillet welds.

Figure 3 (*f*) shows a typical plate girder bridge in which the depth of the girder is increased over the pier supports. Notice that the vertical stiffeners are omitted on the fascia side so as to produce a cleaner appearance. Vertical stiffeners are on the inboard side of the girder. Quite a few of these bridges are constructed in which the girders are of uniform depth throughout.

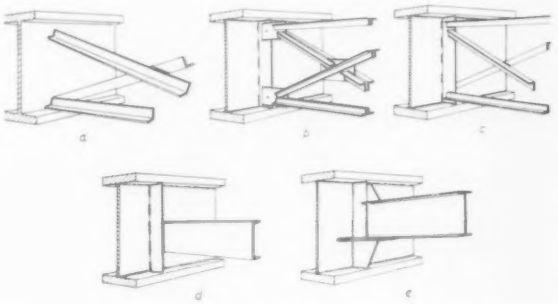


Fig. 4 These typical diaphragms each have their advantages

Diaphragms

Many types of diaphragms are used in welded highway bridges, each apparently with an advantage of its own. A typical method of connecting wide-flange rolled-beam girders is by means of angles which have been cut to length in the shop and are dropped into position in the field, Fig. 4 (*a*). Field erection is easy because the angle may be moved slightly up or down to produce a tight fit to the web of the girder. This type of cross bracing is frequently used on bridges whose longitudinal members are wide-flange rolled beams. In Fig. 4 (*b*), a similar system of bracing is used on fabricated plate girders in which the angles are attached to the stiffener of the girder. In Fig. 4 (*c*), this particular bracing has been shop fabricated as a unit and then these are erected in place and held with an erection bolt until final field welding is accomplished.

In Fig. 4 (*d*), a channel member is used as a diaphragm and is bolted temporarily to the web of the fabricated plate girder and then, in turn, field welded. In Fig. 4 (*e*), the floor beam is attached rather rigidly to the longitudinal plate girder by means of additional web plates and gusset plates. This particular example could be made by welding additional gusset plates to the original vertical stiffener of the plate girder, or the seat plate may be shop welded to the web of the plate girder with the additional bracket placed below and the short stiffener placed above. This would require a small amount of vertical fillet welding and some flat

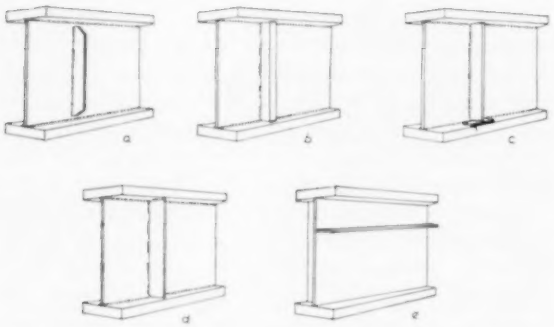


Fig. 5 Examples of stiffeners used in recent bridges

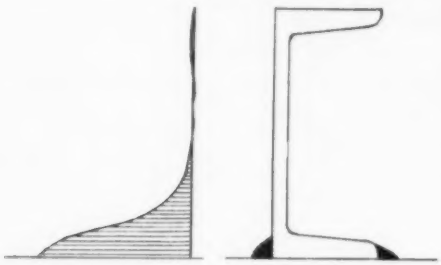


Fig. 6 Forces on shear attachments are high near the girder flange. Channels make an efficient shape

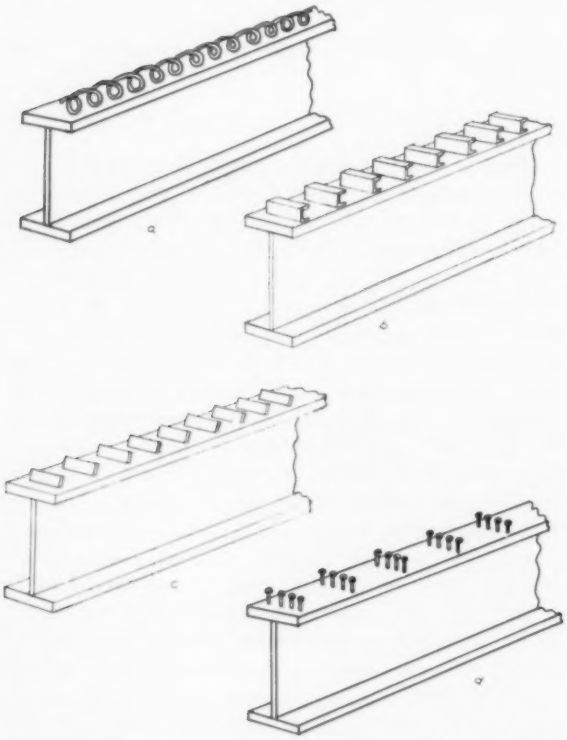


Fig. 7 Different types of shear attachments each have advantages

fillet welding in the field to complete the connection.

Stiffeners

Paragraph 2.10.30 of the AASHO says that, "Intermediate stiffener angles shall fit sufficiently tight to exclude water after being painted." Some of the bridges constructed recently have had the intermediate vertical stiffeners cut short by about an inch on each end as illustrated in Fig. 5 (*a*). This offers an easy method of welding and still allows ample room, so that there is no problem in painting or trapping water.

In Fig. 5 (*b*), angle stiffeners are used and the outside leg of the angle is welded to both the top and bottom flanges. Since this welding is longitudinal to the flange, it avoids any transverse welding on the tension flange.

In Fig. 5 (*c*) is a detail used on the recent Cattaraugus Creek Bridge of the Erie Thruway, in which a 4- x 10-in. plate was welded to the lower tension flange with longitudinal fillet welds. The intermediate vertical stiffener was then placed in position and, in addition to being welded to the web, was also welded to the top compression flange and the bottom insert plate. By this means, there was no transverse welding on the tension flange. Figure 5 (*d*) shows a rather widely used system in which the stiffener fits in loosely and is pulled down tight to the bottom tension flange, and the end of the stiffener is then welded to the top compression flange. By this means, the stiffener is rather tight to both flanges and is accomplished without too much difficulty in getting it into position.

Longitudinal stiffeners (Fig. 5 (*e*)) are allowed and sometimes this has been done on the outside for a more pleasing appearance, rather than using the conventional vertical stiffeners. Where longitudinal stiffeners are used, it is important that they be backed up on the other side with vertical stiffeners. Otherwise, there would be some difficulty in maintaining a flat web as a result of the welding of the longitudinal stiffener on only one side of the web.

Shear Attachments

Recently some work has been done at the University of Illinois in regard to the proper shear attachments which are welded to the top flange of plate girders for composite construction. It has been found, as a result of their work, that the forces on the shear attachments are rather high near the flange of the girder and very rapidly drop off to a small value away from the plate girder. This is illustrated in the following example of a channel shear attachment, see Fig. 6.

As a result of this investigation, it has been recommended that the bottom flange of the shear attachment be as large as possible to take the high shear reaction, that the web of the channel be as thin as possible, and that the upper flange of the channel be used simply to hold the concrete down. This work indicated that the channel section was, perhaps, the most efficient of the available rolled sections for shear attachments.

In Fig. 7 are shown four examples of typical shear attachments. Most states accept all types of attachments. It is generally up to the fabricator to prove that his particular attachment is satisfactory. Figure

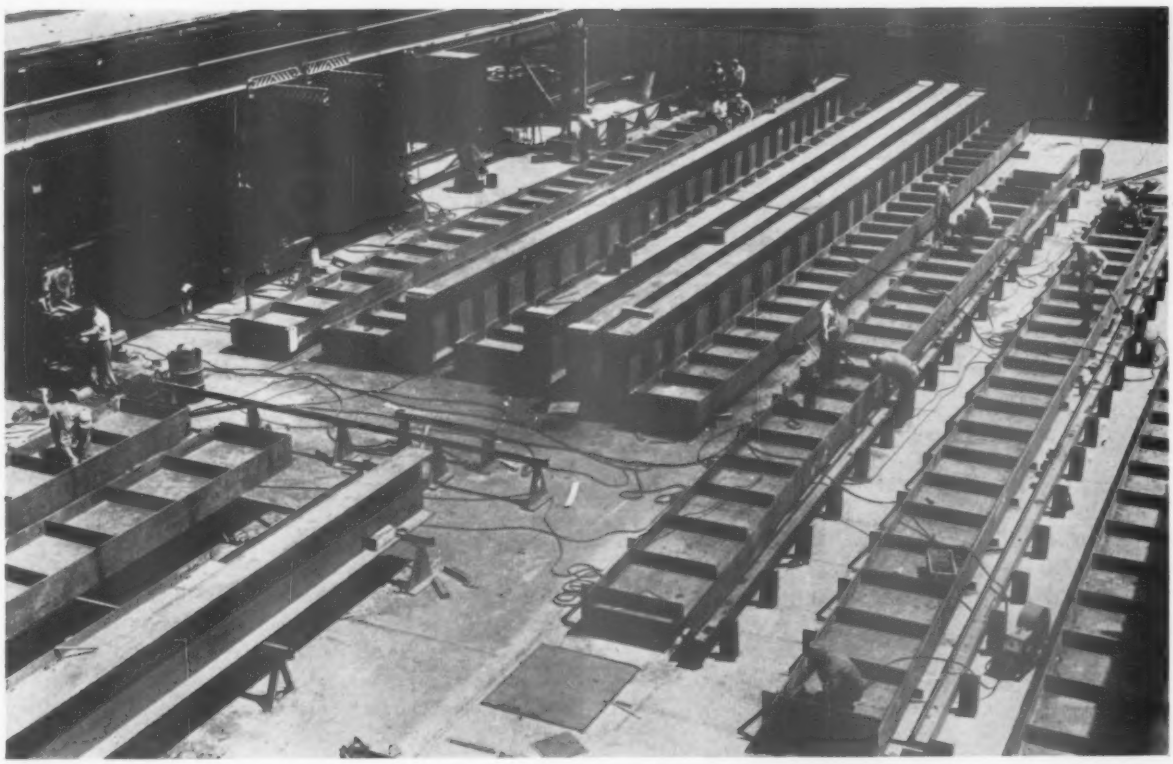


Fig. 8 Girders here are fabricated by assembling in a floor jig. Flanges are brought into tight alignment with pressure applied through jacks

7 (*a*) shows that spiral type of connection. Figure 7 (*b*) illustrates the flat bar which is not quite as efficient, based upon weight of attachment used and, therefore, is rapidly dropping out of the picture. Figure 7 (*c*) is the channel section which is used quite often today. Figure 7 (*d*) shows the use of the stud connections which have been used in some states.

Girder Fabrication

There are two rather basic methods of fabricating a welded plate girder. In Fig. 8 is shown one method in which supports are laid out, so that the web plate is supported at the proper height above the floor. Along both edges of the girder is some form of permanent support against which the flange plate is dropped in the vertical position with one edge resting on the floor. There are many ways of applying pressure through this type of jig, so that the flange plate can be brought into tight alignment with the web plate. This unit is then tack welded and web stiffeners may or may not be applied at this time. In all cases, shop butt welds of either the web or flange plates are made before final assembly. Notice on the lower right-hand corner the use of the semiautomatic welder for welding stiffeners to the web plate, as well as the flange to the web, in this particular case.

In Fig. 9 is shown a simple vertical jig in which the bottom flange plate is placed, so that it lies a few inches above the floor. Small angles were previously welded

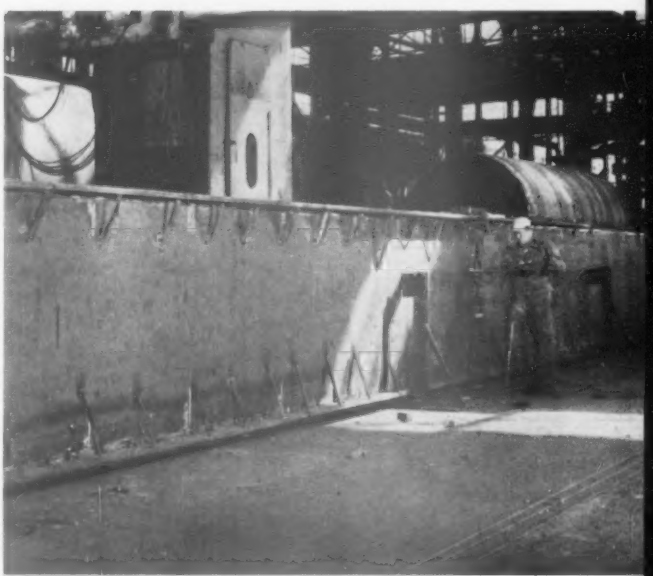


Fig. 9 This is a simple vertical jig for assembling girders. Small angles help position flanges and webs which are tightened for tack welding with a turnbuckle

to the flange near the center line. The web is then placed into a vertical position on top of the bottom flange in the jig. Small angles are also tack welded to the flange on the other side of the web and, by means

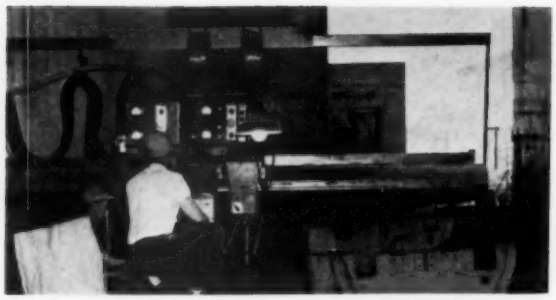


Fig. 10 Girders may be placed in rotating positioners for automatic welding. After positioning, half circles are swung open to permit passage of the welding heads

of wedges, the web is brought into proper position.

Wedges are driven in between the bottom flange and the floor, so that the bottom flange is brought up tight against the web. The web is then tack welded to the bottom flange and additional bars are temporarily welded on one side of the girder, so as to properly hold the flange in position.

Small angles were welded on the top flange plate and this placed on the top edge of the web and tack welded. To obtain a tight fit, a yoke is placed over the whole girder, as shown by the man in the figure, and the turn buckles tightened up, so that pressure is applied to bring the top flange tight against the web.

After tacking the plate girder together, there are numerous ways of positioning the entire unit for automatic welding. In Fig. 10, a special fixture is used to position the plates, as well as to hold them in proper alignment. The two halves of the fixture are closed to form a perfect circle, and these, in turn, are mounted on rollers, so that the entire unit can be rolled around into the proper position. Then the half circles are swung open, so as to afford a clear path for the automatic welder. In some cases, trunnions are tack welded to the end of the girder, and the whole unit is allowed to swing into position.

For some larger girders, especially those which have a deeper section over the pier supports, the girder is simply laid up against some vertical supports so that it rests at an angle of about 45° for proper positioning under the automatic welder (Fig. 11).

Field Welding

Figure 12 shows three possible methods of preparing the edge of the girders for field welding. Perhaps the most difficult and older method is shown at (*a*) in which the two butt welds in the flange and butt weld in the web occur at three different planes. This is difficult because three particular planes of preparation must be made and yet the two ends must meet close when put into position for welding in the field. Perhaps the ideal method would be (*c*) in which all three

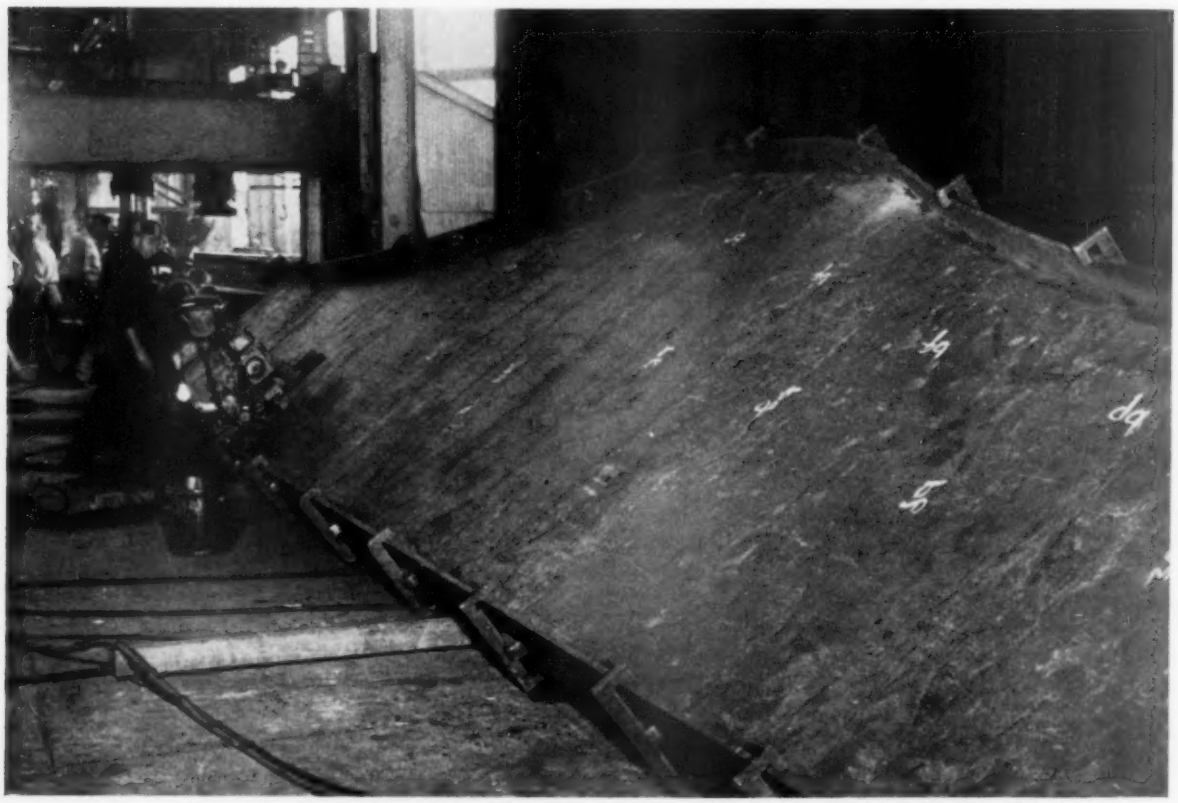


Fig. 11 Some large girders are simply angled against supports to position joints for automatic welding

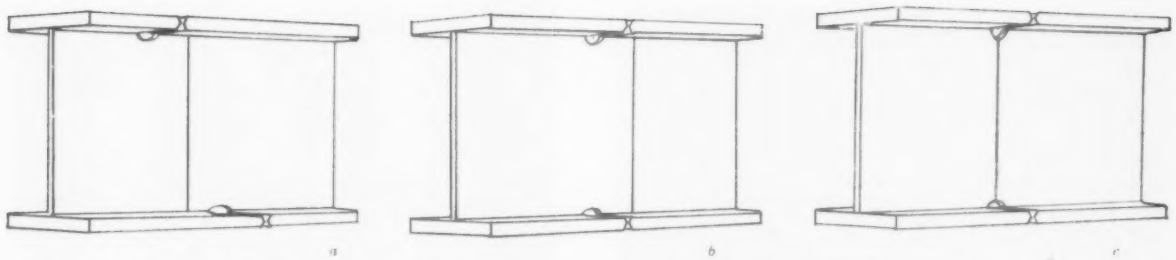


Fig. 12 Three possible methods are shown for preparing the edge of girders for field welding

butt welds are prepared in the same plane, since this would be easier to lay out. This has been used to quite an extent in the more recent bridges. It has been brought out that joint (*b*), in which the two flange welds are in the same plane, but the weld in the web is moved slightly, might offer a small advantage, since there is available a method of supporting one girder upon the other during the field erection.

Paragraph 504 of the AMERICAN WELDING SOCIETY Bridge Codes specifies that "in making butt welded splices in rolled or built-up members, web splices shall be welded before flange splices, unless otherwise approved by the engineer." The experience of various fabricators and bridge engineers with this specification indicates that this might lead to some difficulty for three reasons:

1. If the web is completely welded first and then the welds of the flange are finished later, this will result in some residual tensile stress left in the flange and, if possible, should be avoided, especially in the tension flange.

2. If the web is completely welded first, some fabricators have experienced the difficulty of the web buckling as a result of the shrinkage of the welds in the flanges which were made later.

3. If the web is completely welded first, some erectors have experienced difficulty because the ends of the girder might lift up, due to the shrinkage effect of the vertical-up welding.

On the other hand, it is not a good idea to swing entirely in the other direction and completely weld the flanges first and then weld the web last because the web now will be under tension and, in certain cases, this might offer some difficulty with portions of the weld in the web cracking because of the rigidity of the previously welded flanges. The best course to follow appears to be a compromise, in which a portion of both flanges is welded first, then part of the web is welded. Then the flange is finish welded, and the small amount of welding left on the web is completed. Procedures commonly used follow a similar sequence.

Erection

The unsupported length of a plate girder using diaphragms is not excessive after the final erection. Although this final L over b ratio is not excessive, quite often the plate girder during the erection will have an L over b ratio which is excessive because of its long unsupported length and will not have sufficient lateral stability. In this case, the girder can be stiffened by means of steel cables and angle bars connected, as shown in Fig. 13.

Fig. 13 Long girder shown is stiffened by cables for erection

Fig. 14 Special clamps on bottom flanges will offer temporary support for girder about to be raised into position

In Fig. 14, the ends of the girders cantilevering over

the pier supports are ready to receive the new girder which is about to be hoisted from below. Notice that special clamps have been temporarily bolted to the bottom flange of the girders and these, in turn, will offer temporarily support for the new girders, which are to be placed in position. The State of Texas has done an outstanding job in working with their fabricators and erectors in working out details, so as to assure good workmanship. Part of the result of this effort has been the making of special clamps, such as the ones shown here (Fig. 15). These clamps are made out of so-called welders' clamps and are welded to bars in various manners. In this particular example, the lower clamp is used to hold the flanges of two girders in position, and the set screws at the bottom are to be used in case there is a slight offset in the flanges. The top clamp will give some lateral adjustment.

For heavier plate girders, perhaps above 54 in. in depth, additional support is required over that offered by the clamps just described. One practice is to weld a 1- x 4- x 16-in. plate to the supported girder, and the supporting girder has two small lugs attached on the top flange directly over the web. This forms a good locating device and is sufficiently strong to withstand the weight of the plate girder.

Another good idea, from the Texas Highway Department, is the use of spacers made by welding a turnbuckle between two long tubular sections on the ends of which are weld clamps. The spacer is clamped to two girders, and, by means of turning the turnbuckle, proper distance can be obtained and held during the actual erection.

Conclusion

Welding may be applied with advantage to all types of bridges. Welded steel will produce joints and connections as strong, if not stronger than the rest of the member. No longer must designers consider the efficiency of a joint; no longer must designers deduct rivet holes or bolt holes. Whatever physical property the member has, the welded joint will match it. Welding is strong and dependable. If it is so designed and applied properly, it is low in cost. Because there are no limitations placed on welding, the bridge engineer is not inhibited or restricted in his thinking. Because of this new freedom in design, there have been some rather unusual and unique bridges in the last few years as a result of welding. More and more states are accepting the specifications as set up by the American Welding Society. More and more bridge engineers are making use of these standard specifications. They are dependable and yet simple and easy to apply.

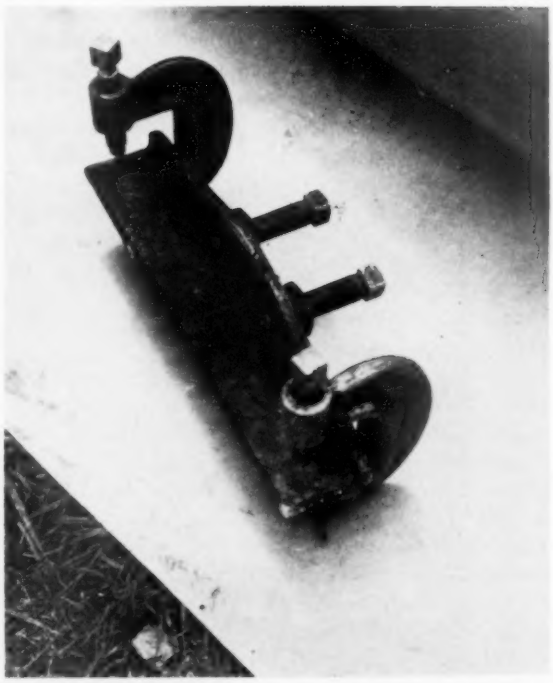


Fig. 15 Texas Highway Department personnel have devised numerous special clamps to aid in erection. Girder flanges, when clamped, can be brought into alignment with the set screws

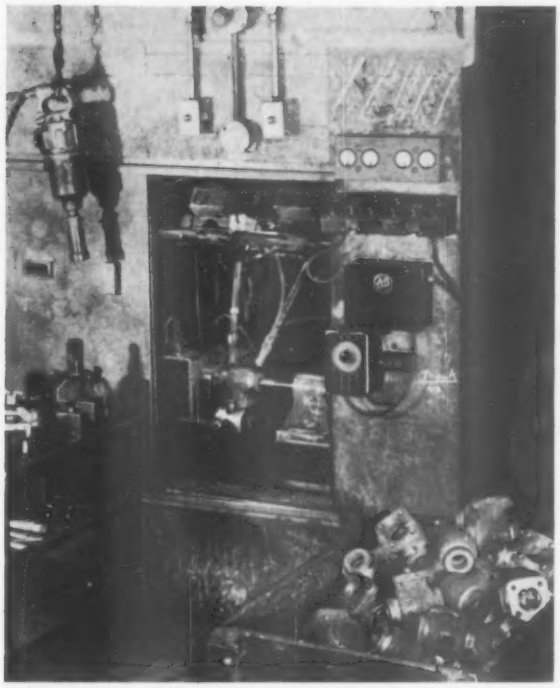


Fig. 1 Welding booth with sliding door and peephole. At the right is control panel from which exhaust hood, welding lathe, starting button and timer are controlled

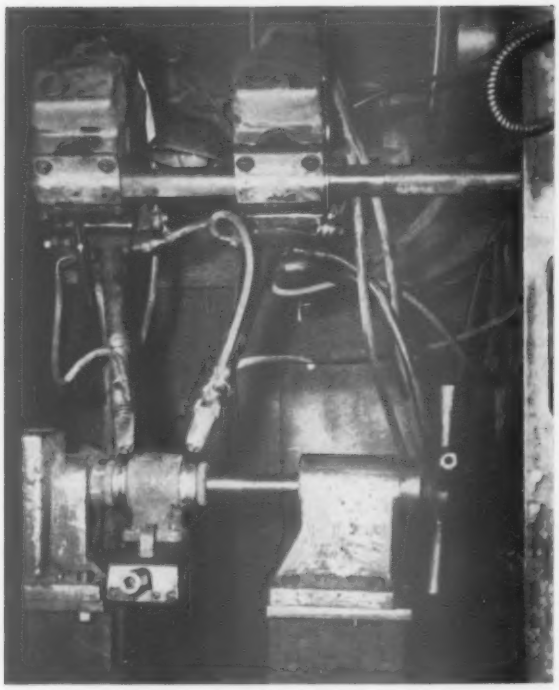


Fig. 2 Close-up showing welding head fixtures and welding lathe with adjustable tailstock

GAS-SHIELDED METAL-ARC WELDING OF HIGH-PRESSURE VALVES

Inert-gas process found to be ideal for improving weld quality and producing the desired cost reduction of the product

BY FRED R. ZACHEUS

Introduction

In manufacturing high-pressure valves (over 600 lb pressure), three prime requisites, all of equal importance, must be considered to insure maximum serviceability of the product while still maintaining minimum fabrication costs. These requisites are: (1) excellent and uniform weld quality; (2) low unit manufacturing cost; and (3) operator safety.

The accepted method for manufacturing high-pressure valves in the past has been to design the product for manual arc welding and to establish and maintain quality control through the mediums of welder qualification, radiography and either magnetic-particle inspection or visual inspection of cut and etched weld samples. Although this method has produced good results, the handling, pre-weld preparation, manual welding, slagging, cleaning, re-welding and other allied operations have made the over-all manufacturing costs high.

The disproportionate cost of manual welding of high-pressure valves has long indicated to manufacturers that a less expensive method, which at the same time maintains or improves weld quality, must be found.

At the Hancock Valves Division of Manning, Maxwell & Moore, Inc., Watertown, Mass., it was believed that the gas-shielded metal-arc process of welding would be ideal for producing the desired cost reduction while improving weld quality of the product. To establish this, equipment utilizing the process was installed for the purpose of making tests.

Figures 1 and 2 show the layout of the test equip-

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Presented at the 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8–12.

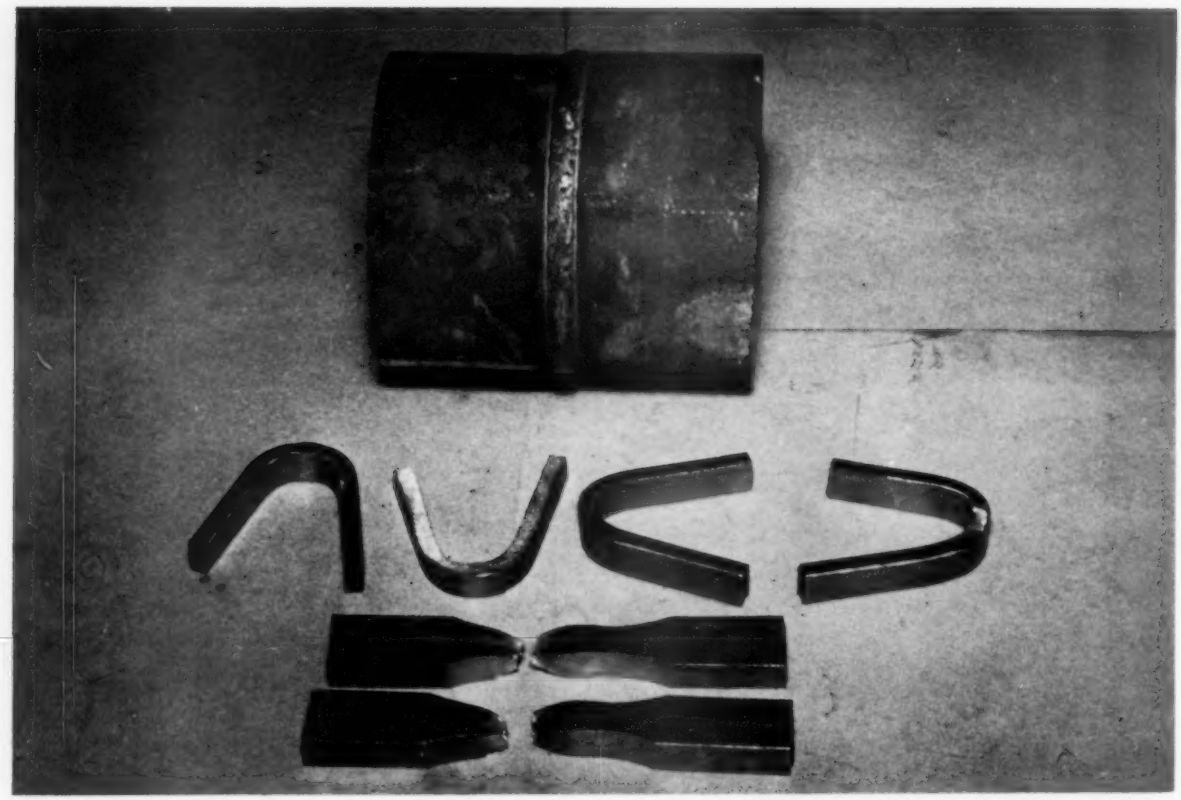


Fig. 3 Physical test specimen. Two reduced-section tension specimens, two root-bend specimens and two face-bend specimens are machined from pipes to test radiographically

ment at the Hancock Division plant.

Process Qualification

As a preliminary step, the manufacturers qualified the process under Section IX of the ASME Boiler Code for inert-gas metal-arc machine welding. The valve parts, under the (P-Number 1) classification of the code, contained the following nominal chemical analysis:

Carbon	0.15 – 0.20%
Manganese	0.60 – 0.90%
Silicon	0.15 – 0.30%
Phosphorus	0.03 max
Sulfur	0.03 max

The 1/16-in. diam filler wire, under weld metal analysis number A-1, was of the following nominal chemical analysis:

Carbon	0.12%
Manganese	0.95%
Silicon	0.45%
Phosphorus	0.025%
Sulfur	0.025%

Figure 3 illustrates the size of the welded test pieces used in the qualification test. After sectioning the pipe and shaping off the backing strip, two reduced-section tension specimens (as per Q-6(b) of the code), two root-bend specimens and two face-bend specimens (as per Q-7.2 of the code) were machined from the pipe. Radiographs taken of these sections showed the weld to be free of porosity, crack voids or other defects. Results of the tensile test were as follows:

Fig. 4 Welding fixture for accurate location of valve parts

	Y.S.	T.S.	Elongation 2 in.	R.A.	Break
Sample 1	60,000	76,000	24.5%	40.0%	OSGM
Sample 2	68,500	75,000	25.0	40.0	OSGM

The tensile bars showed necking at the opposite end of the gage mark from the break.

Face and root-bend tests were excellent, showing no indication of cracking. A hardness survey of the cross-sectioned test piece, using the Rockwell "B"' scale, showed the following results:

Base metal	Heat-affected zone	Weld	Heat-affected zone	Base metal
88–90–90	94	92–90–92	93	90–95–89

On the basis of these qualification tests, it was determined that the gas-shielded metal-arc welding process would produce all results desired by the manufacturer, and, accordingly, welding procedure for full-scale operations was evolved.

Welding Procedure of Product

In actual operation, the hard-surfaced seats are properly located in the body of the high pressure valve by a hardened "master wedge" (Fig. 4). The parts are then placed between centers of the welding lathe (Fig. 5) and pressure is applied through the spindle of the tailstock, holding the seats firmly in line against the "master wedge."

Once pieces have been positioned, the operator closes the door of the welding booth (Fig. 1), the starter button is depressed, and timer, gas and water solenoids, wire feed motors and the variable speed motor which rotates the head stock spindle are energized. After a pre-determined amount of time, the timer cycles out, thus de-energizing the wire feed motors and stopping the lathe rotation. Water and shielding gases continue to flow for three or four seconds after the arc has been broken, thus excluding the atmosphere from the craters.

During welding, the operator has sufficient time both to watch the progress of the arc by means of the welding booth peephole and to assemble a new valve for insertion after the original welding cycle has been completed.

At completion of each cycle, welded valves are replaced by new assemblies and the same procedure is followed again.

Welding Problems and Their Solutions

In perfecting welding procedures, as in all development work, problems occurred in varying degrees of seriousness.

For this particular operation, joint design was of primary concern since its effects would be seen in both the quality of the weld and the cost of the application. After considerable experimentation, checking penetration by cutting and etching, it was finally decided that the included angle of the joint should be as small as possible yet remain consistent with good penetration, fusion and bead contour.

One controlling factor in this decision was "the angle of contact" of the electrode with the groove. This

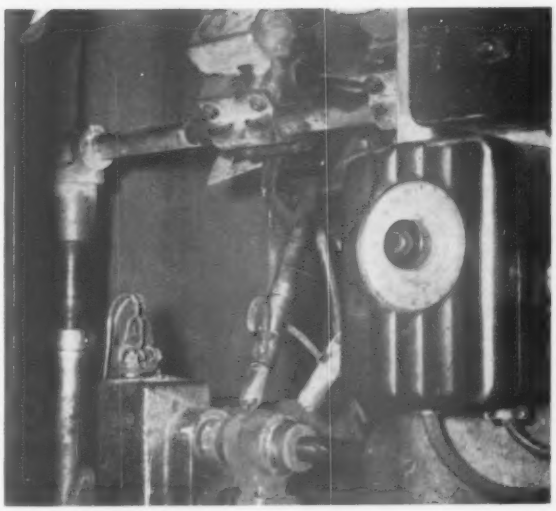


Fig. 5 Valve parts are placed between centers of welding lathe and pressure applied through spindle of tailstock to hold seats firmly in line during welding

angle, measured from the vertical, must of necessity be less than one-half the included angle of the groove. A second controlling factor was "the speed of rotation" of the work which must be synchronized with the correct closed-circuit voltage and amperage settings.

It was found that if "the angle of contact" were to be too far forward, "the speed of rotation" too fast, or either amperage or voltage settings too high, the metal would spill or produce an excessive convex bead. Conversely, it was found that if the "angle" were too far back, "rotation" too slow, or amperage or voltage settings too low, the weld contour would be excessively concave or spill off the opposite side.

To sum up: the included angle of the groove must be opened sufficiently to allow the electrode to produce good penetration and fusion, yet not wide enough to require an inordinate amount of weld metal or cause spillage.

Generally speaking, it was found that root diameters of more than three inches were relatively easy to weld, whereas smaller diameters created difficult problems.

Product Quality Control

In any large scale, repetitive operation, methods of determining quality control are extremely important. From the standpoint of cost, they must be kept to an absolute minimum, while for the sake of quality, they must be rigid and complete. To satisfy both requirements, definite procedures have been carefully established.

The first time any assembly is welded, it is necessary to develop and control all of the variables. Therefore, actual valves are welded, quartered and etched for visual inspection. From this can be determined if the proper penetration, fusion and bead contour have been obtained. In addition to visual inspection of the etched cross sections, it is deemed advisable to cut several thin cross sections, usually $^1/_8$ to $^3/_{16}$ in. thick,

Table 1—Automatic Welding Specification 9W7AW-EW

	Left head	*Right head*
Generator	A129245	A139492
Closed circuit voltage	24 to 26	24 to 26
Closed circuit amperage	375 to 400	330 to 360
Amperage setting	335 to 355	360 to 375
Argon	50 cfh	50 cfh
Oxygen	2 cfh	2 cfh
Arc length control—(panel)	$2^3/_4$	2
Wire feed	High speed	High speed
Polarity	Electrode pos.	Electrode pos.
Distance—contact tube to seat	1 in.	1 in.
Distance—centerline to head	$7^{15}/_{16}$ in.	$8^3/_8$ in.
Distance—front of base to front of fixture	$7^1/_2$ in.	$7^1/_2$ in.
Distance—fixture height	47 in.	47 in.

Passes—3
Lathe speed—4 rpm
Reeves setting—$3^1/_2$
Groove width at top—$^5/_{16}$ in.
Root width—$^1/_{16}$ in.
Groove depth at $^9/_{32}$ in.
Groove angle—30° included
Wire used—$^1/_{16}$-in. diam A 675
Timer—47 sec

which are bent through the root of the weld for a further check on root cracks, poor penetration or poor fusion.

Both etched and bent specimens are inspected by the welding foreman, chief inspector and welding engineer. If not acceptable, settings are changed, and additional welds are made until the process is acceptable to all parties.

When welding does meet requirements, a welding specification sheet (Table 1) is made out in quadruplicate for the engineering and inspection departments and the welding foreman and welding engineers.

This form then serves as a guide to be used whenever ensuing valves of the same size are placed in production in the welding shop.

As a further check on the quality of the product, an inspection procedure has been established for use during actual welding. After inspection of the first piece has been concluded and passed, the correct closed circuit voltage and amperage ranges are posted on the welding booth for the convenience of the operator in checking work "in progress." Each hour's production is segregated and held until passed by the welding inspector. To insure good quality, the inspection department regularly quarters and etches samples, and should the quality prove unsatisfactory, production is immediately halted.

A third check is conducted by subjecting assembled valves to a hydrostatic pressure test of $2^1/_2$ times the rated pressure of the valve. In this case, each valve is tested at 2000 lb pressure. Any indication of "weeping" is cause for rejection.

Since standardizing on automatic welding, the percentage of leakers through the weld has been reduced practically to the zero point.

Second Phase—Cost Analysis

With the gas-shielded metal-arc method of welding, a substantial reduction in unit manufacturing costs has been realized while at the same time making a vastly superior product.

In using the new welding process, it has been found unnecessary to employ protective material prior to welding to facilitate post-weld cleaning, as is customary when manual welding is employed. A 70% reduction in the time required to remove weld spatter and other allied operations has also been realized.

With welding speeds so much higher they are no longer the controlling element of the time study, only handling remains a critical problem. Therefore, effort and methods to reduce the handling time become very important.

Third Phase—Operator Safety

With the increased production rate which results from use of any automatic setup, greater emphasis must be placed upon operator safety.

Due to the higher amperage and voltage settings of the gas-shielded metal-arc process in comparison with manual welding, arc density becomes more concentrated. The manufacturer of this welding equipment recommended the use of an extra filter plate, in addition to the regular welding plate, to remove the harmful infrared and ultraviolet rays. This added safety measure was built into the peephole of the welding booth (Fig. 1). By having the edges of the sliding door of the booth encased in channels, all chances of ray leakage from the booth were eliminated. The operators also wear flash goggles.

All welding fumes are exhausted outside the building by a blower connected to the top of the welding booth.

Conclusions

By using the gas-shielded metal-arc welding process to fabricate high-pressure valves, the following has been accomplished:

1. Improvement in uniformity and quality of welds, by:
   (*a*) better control of penetration and fusion.
   (*b*) elimination of hydrostatic leakers through better seat alignment as well as absence of porosity and slag inclusions.
2. Substantial reduction in unit costs, due to:
   (*a*) reduction in direct labor cost.
   (*b*) elimination of pre-weld spatter protection.
   (*c*) reduction in post-weld cleaning.
   (*d*) accurate preparation of setup sheets to reduce future setup time.
   (*e*) less time spent in repairing leakers.
3. Better operator safety, specifically:
   (*a*) elimination of eye injuries due to flashes,
   (*b*) more comfortable conditions.

Acknowledgment

The author wishes to acknowledge the helpful suggestions and constructive encouragement offered him by A. J. McDonald, Manufacturing Engineer, and Charles Wolejko, Welding Foreman, Hancock Valves Division, Manning, Maxwell & Moore, Inc., Watertown, Mass., in the preparation of this paper.

SUBMERGED-ARC WELDING GOES TO SEA

Construction at an eastern shipyard features submerged-arc welding applications. This process is used on a supertanker to join the deck subassembly and make transverse butt welds in the wing deck (see Figs. 1 to 3).

In both operations, the steel plates are double-beveled. After the undersides are manually welded, the top sides are joined by the submerged-arc welding process. The automatic welding reaches a speed of 14 ipm.

Based on a story by the Linde Air Products Co., New York, N. Y.

Fig. 1 With the operation performed on board ship, a transverse butt weld is made in four passes on the top side of the wing deck

The operator follows along behind the weld and lifts off the solidified composition. Thickness of the plate is $1\frac{9}{16}$ in.

Fig. 2 This shows the second and final pass in submerged-arc welding the deck subassembly for the supertanker

The subassembly, which consists of 1-in. thick steel plate, is fabricated on the ground and then transferred to the ship.

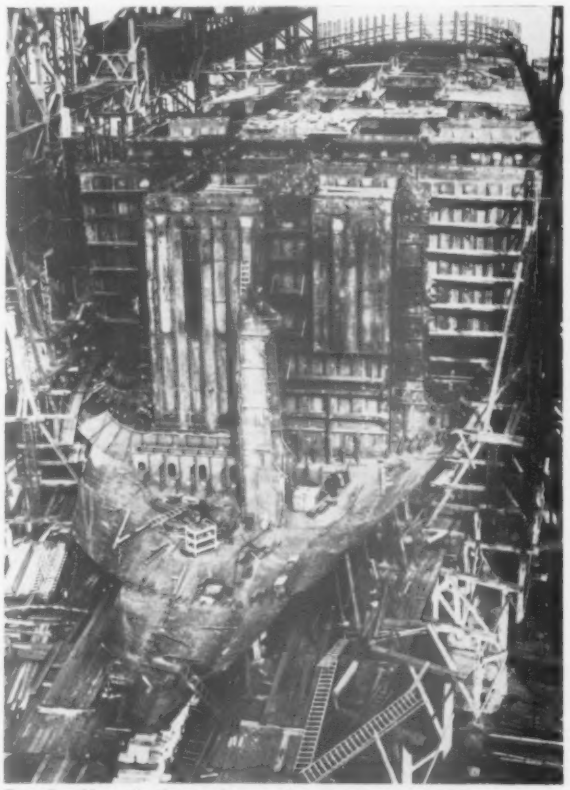


Fig. 3 Here is the tanker under construction at an eastern shipyard

The bow section is constructed on the ground and then joined to the hull by manual welding

LAUNCHING A WELDED ALUMINUM YACHT

Welding lends a hand to pioneer-builder of fine boats

BY G. E. WENDLANDT

The Burger Boat Co., Manitowoc, Wis., was founded in 1863 and, from the very beginning, concentrated on building fine boats of the finest available material. Over 30 years ago, this company was one of the first yacht builders to see the potentialities of the steel hull.

G. E. Wendlandt is associated with Air Reduction Sales Co., Milwaukee District.

Fig. 1 A 36-ft welded aluminum cruiser

Today, Burger is one of those taking the lead in welded aluminum alloy construction, with the 36-ft cruiser shown on these pages, Figs. 1 to 3, and two 57-ft yawls, all three made of aluminum.

The first to be launched was a yacht 36-ft over all with an 11 ft beam and a 2 ft, 6-in. draft. The hull ribs and plates, decks, deck beams and bulkheads are of aluminum, as are the frames, keel and other structural members. Engineered for strength with a minimum of weight, the 36-ft yacht has less displacement than a comparable boat of wood construction. Shakedown tests proved aluminum provides easier maintenance and lower operating costs.

Heart of the all-welded job were two gas-shielded metal-arc welding guns using $^{3}/_{64}$-in. aluminum filler wire.

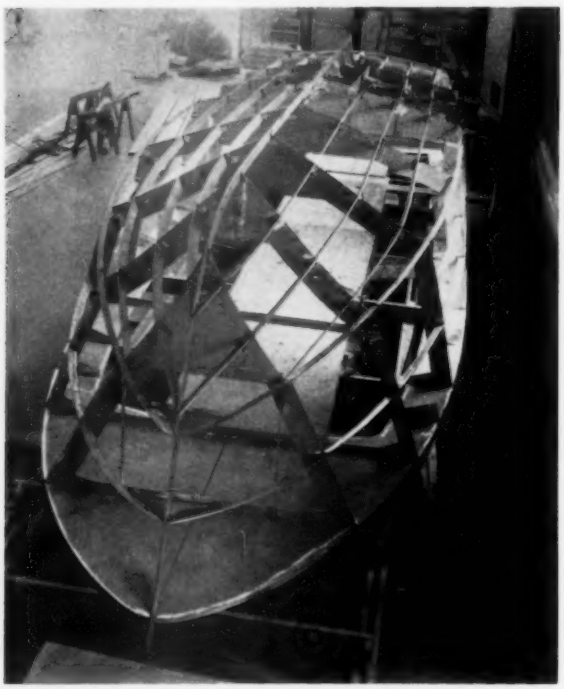


Fig. 2 The gas-shielded metal-arc process was used to weld this all-aluminum yacht from hull to decks

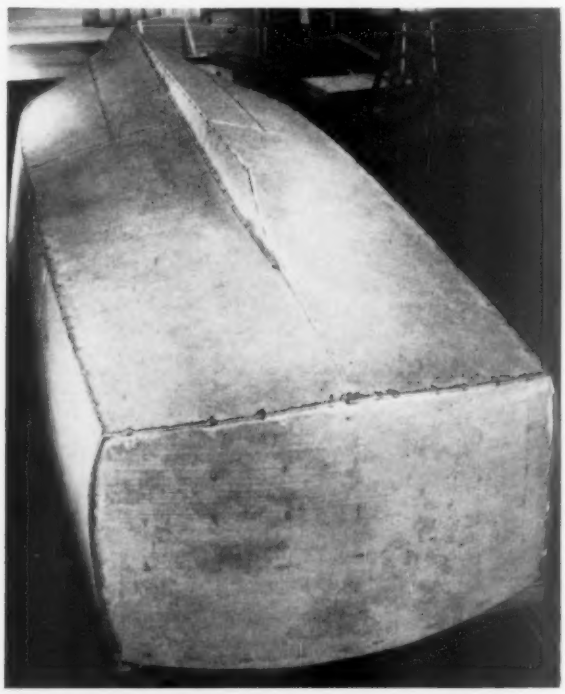


Fig. 3 Finished hull of 36-ft cruiser showing welded construction. Ribs, plates, decks, beams, bulkheads are all-aluminum

PLUG-WELDING JOB SIMPLIFIED BY CO_2 PROCESS

The Chicago Steel Tank Co., a division of U. S. Industries, Inc., found itself confronted with a development that challenged its ingenuity to develop a more efficient plug-welding technique than those commonly employed. The situation was brought about by the simultaneous scheduling through the plant of several steam-jacketed stainless vessels involving thousands of stay bolts with 1-in. plug welds (see Fig. 1).

The coated-electrode hand-welding method involved high labor costs. Automatic welding was found to be acceptable by experimentation with submerged-arc method but other elements of cost such as fitup and positioning made this method prohibitive. Metal-arc inert-gas welding method was unsatisfactory because of difficulties experienced in obtaining good penetration.

After conducting numerous experiments, the more efficient plug-welding technique was developed by adapting an active-gas-shielded consumable-electrode welding process (see Fig. 2).

The higher degree of efficiency obtained was due to several factors. More important were the increased metal deposition rates and the increase in penetration resulting from the low-popping agitation type of arc that is characteristic of welding-grade carbon dioxide.

At the same time, this new technique permitted greater operator control, minimized the need for rework and greatly enhanced the appearance of the welds (Fig. 3).

Based on a story by Chicago Steel Tank Co., Chicago, Ill.

Fig. 2 CO_2 plug welding of jacketed heads provides improved weld quality and appearance

Since arc control is the key to quality, the need to properly control spatter, weld bead and consistency of penetration, determined that conventional welding equipment did not give satisfactory results. The end result was a constant-voltage motor-generator power unit, simplified constant-speed wire-feeding device, proper welding-grade CO_2, regulating equipment, and manual gun with built-in finger-tip control.

The optimum specification for this type of operation proved to be 35 cu ft per hr of carbon dioxide and a speed of 500 ipm of an approved type electrode with an arc voltage of approximately 42 volts at a level of 400 amp.

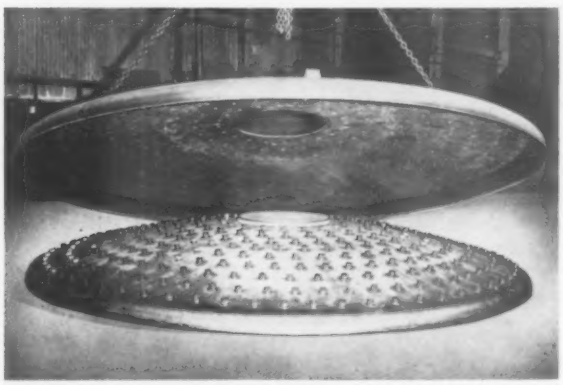


Fig. 1 Fitting of two heads prior to CO_2 welding

Fig. 3 Close-up of a completed CO_2 plug weld

Society News

1957 Annual Meeting and Exposition Hailed As Best in History of AWS

New attendance records established in Philadelphia during week of April 8.
AIEE Committee on Electric Welding contributes to success

All-time highs in attendance and interest were recorded at the AMERICAN WELDING SOCIETY Adams National Meeting and the concurrent Fifth Annual Welding Exposition. The meeting and show were held in Philadelphia, Pa., April 8–12, 1957. According to official registration figures, 11,254 visitors attended the 3-day exposition and 1839 engineers participated in the technical sessions. The meeting, named in honor of Dr. Comfort Avery Adams, a founder and first president of AWS, was the 38th annual meeting of the SOCIETY.

A dinner honoring Dr. Adams was featured by the presentation to him of an oil portrait of himself as a gift of the SOCIETY. In a telegram, read at the dinner, President Eisenhower said: "Dr. Adams has achieved an outstanding record of public service and has won the abiding esteem and affection of his fellows in the engineering profession. His career is an inspiration and a challenge." More than 600 guests attended the dinner.

All other activities of the meeting were also well attended. Plant tours to Westinghouse Electric Corp. and the U. S. Steel Fairless Works attracted more than 200 visitors each. More than 100 women were registered for the week's special program of ladies' activities.

Fig. 1 Registration area was a busy place all week long. Eighteen hundred and thirty-nine (the largest number ever) members and guests signed up for attending the technical sessions and other convention activities

Officers Elected

The week's program started with the National Business Meeting, Monday, April 8th. Following an address by AWS President John J. Chyle, the full text of which is given in later pages, a new slate of officers was formally elected and introduced to the membership. New officers will be inducted June 1st.

The new officers, as reported upon fully in the May issue of THE WELDING JOURNAL, are as follows: President, Clarence P. Sander; First Vice-President, G. O. Hoglund; Second Vice-President, Charles I. MacGuffie; Treasurer, Harry E. Rockefeller.

Directors-at-Large are: Alfred E. Pearson, Clarence Styer, Robert M. Wilson, Jr., and James F. Deffenbaugh.

Elected as Regional Directors were: District 3, North Central, Harry E. Miller; District 5, East Central, Lew Gilbert; District 7, West Central, Alfred F. Chouinard; District 9, Southwest, Percy V. Pennybacker; District 11, Northwest, Charles B. Robinson.

Awards Presented

The presentation of five national and eighteen regional awards highlighted the opening session.

Fred L. Plummer, director of engineering, Hammond Iron Works, Warren, Pa., was named as winner of the Samuel Wylie Miller Memorial Award. The honorary medal and certificate was presented to Mr. Plummer for his outstanding contributions in the application of welding to storage tanks and to the advancement of engineering technology in the shop and field fabrication of welded structures.

This year's Adams Lecturer was DeWitt C. Smith, chief metallurgist, Harnischfeger Corp., Milwaukee, Wis., who was presented with a certificate and honorarium upon the presentation of his special paper on the subject of the welding of the ultra-high-strength steels. The lecture is named after the founder and first president of the AMERICAN WELDING SOCIETY.

Honorary membership in the SOCIETY was awarded to O. B. J. Fraser, assistant

Fig. 2 President J. J. Chyle, 1956–57, opened the Annual Business Session on Monday morning with his address outlining the progress, the universal use and the future of welding

Fig. 3 On Monday morning, at a crowded Opening Session (many standing), the 1957–58 Officers were symbolically inducted and the annual Adams Lecture was presented. Also, the Society Awards were bestowed

Fig. 4 During the Annual Business Session, at the time of the symbolical induction period, President J. J. Chyle, 1956–57, turned over the president's and chairman's gavel to President-Elect C. P. Sander, 1957–58

manager, Development and Research Div., International Nickel Co., New York. The award was made for exceptional accomplishment specifically in connection with the joining of nickel and nickel alloys. Mr. Fraser, formerly president of AWS, has also served the SOCIETY in many other capacities.

The 1957 J. F. Lincoln Gold Medalist was Jay Bland, project engineer, Engineering and Research Dept., Standard Oil Co. (Ind.), Whiting, Ind. The award is granted the individual who has written the paper judged to be the best published in THE WELDING JOURNAL.

The National Meritorious Service Award went to A. N. Kugler, chief welding engineer, Air Reduction Sales Co., New York. The award was given for the outstanding service Mr. Kugler has rendered to the AMERICAN WELDING SOCIETY for many years.

The awards program concluded with the presentation of eighteen regional Meritorious Service Awards. The recipients were: Howard E. Adkins, Leon C. Bibber, Ralph D. Bradway, Irving H. Carlson, Roger W. Clark, Thomas J. Crawford, E. Paul DeGarmo, Walter G. Dick, Frank G. Flocke, Robert E. Kemp, George G. Luther, Thomas McElrath, P. Gordon Parks, Clarence P. Sander, Gilbert S. Schaller, Alton G. Thompson, J. Raymond Wirt and Allen E. Wisler.

AIEE Participation

Another highlight of the opening session was a brief but effective address by C. T. Pearce, vice-president of the American Institute of Electrical Engineers. Mr. Pearce welcomed all AIEE members to the joint SOCIETY convention, and stressed the importance and value of such a cooperative effort, particularly at the time of the Adams National Meeting. He recalled, with pleasure, that Dr. Adams is the oldest living past-president of AIEE.

Technical Sessions

More than fifty technical papers were presented at the eighteen sessions of the Adams National Meeting. Of these, three sessions were co-sponsored by the AIEE Committee on Electric Welding. Subject matter in the technical sessions ranged from the everyday welding problems of industry, through special papers pertaining to nuclear energy and the newer metals such as titanium and zirconium, to specialized research problems.

This year, as an innovation, bound copies of abstracts of the papers were made available. Their popularity was such that the supply was quickly exhausted.

Here is how the technical program was broken down:

Nuclear Reactors and Radiation Effects, two sessions at which six papers were presented.

Weldability and Research, three sessions at which seven papers were presented.

Applications, three separate sessions were devoted to the broad subject of application of welding with a total of nine papers.

Fig. 5 President-Elect C. P. Sander, 1957–58 delivered his "acceptance" of the election to the presidency, stressing his conviction that the Society would continue to progress in the future as it has in the past

Fig. 6 The past-president's certificate, lapel pin and commemoration gavel and block were presented to outgoing President J. J. Chyle, 1956–57, by Past-President J. H. Humberstone, toward the close of the Annual Business Meeting

Resistance Welding, three sessions with nine papers on various aspects of the subject including new control devices.

Brazing, Soldering and Surfacing were highlighted in two separate sessions at which six papers were heard.

Titanium and Zirconium were the principal topics at an exclusive session during which three special papers were presented.

Other subjects to which special sessions were devoted are: *Pressure Vessels, Gas-Shielded Welding, Arc Welding* and *Structures.*

Exposition

The Fifth Welding Show will probably be remembered as the occasion when the welding industry took its first giant step into the ranks of the major industries of the country.

While President John J. Chyle was pointing out that sales of welding equipment and accessories are rapidly approaching the magic point of one billion dollars in annual sales, the show itself became one of the nation's major industrial expositions.

With 119 companies using 33,000 square feet of exhibit space, the show is now among the first 25 annual industrial expositions in the country.

The 11,254 visitors who crowded the aisles set a new attendance record, a shattering 44% higher than the previous high of 7800. This total did not include hundreds of students from universities,

Fig. 7 American Institute of Electrical Engineers Vice-President C. T. Pearce welcomed all AIEE members to the joint Society convention, and stressed the importance and value of the joint Society collaboration, particularly at the time of the Adams National Meeting. Dr. Adams is the oldest living Past-President of AIEE

Fig. 8 The National Meritorious Certificate Award was bestowed upon Arthur N. Kugler in recognition of his counsel, loyalty and devotion to the affairs of the Society, his assistance in promoting cordial relations with industry and with other organizations, and his contributions of time and effort in behalf of the Society

Fig. 9 Each year the Society bestows Meritorious Certificate Awards to a group of members who, in the opinion of the Sections and Districts, have performed signal service to the Society

Here are those who were present to receive their awards in Philadelphia. *(Left to right) First Row*—H. E. Adkins, L. C. Bibber, R. D. Bradway, I. H. Carlson, T. J. Crawford, President Chyle, W. G. Dick, F. G. Flocke, R. E. Kemp; *second row*—A. G. Thompson, J. R. Wirt, President-Elect Sander, P. G. Parks, G. G. Luther and Tom McElrath. (R. W. Clark, E. P. DeGarmo, G. S. Schaller and A. E. Wisler also won awards, but could not be present to receive them personally.)

vocational, trade and high schools in the area and from a number of distant states.

It soon became apparent to visitors that many manufacturers are now using their booths at the exposition as a showplace to unveil new products and new models. Hundreds of visitors commented on the fact that they were seeing dozens of new products, any one of which might prove of sufficient value to their factories to make the visit worth while.

Trade papers in the welding and metals fields also gave outstanding recognition to the show by devoting special editions to welding, and more reporters were present than ever before.

Many Delaware Valley companies sent out their welders in some numbers to see the show but, for the most part, visitors tended to come from the upper echelons of industry. One notable characteristic of the 1957 show was that, unlike the previous four expositions, the floor was most crowded during business hours, rather than during the evening periods.

The show was opened with President-Elect Clarence P. Sander cutting a heavy marine chain draped across the entrance. Within minutes thereafter, the crowds awaiting admission were backed up more than 100 deep in seven lines awaiting their badges of admission.

Every type of welding equipment and accessory was represented on the floor of the show by the manufacturers, and this permitted visitors to get the type of information they needed regardless of the nature of their company's operation.

Fig. 10 Jay Bland was the recipient of The James F. Lincoln Gold Medal and Certificate, awarded for the paper published in The Welding Journal during the previous year which constituted the greatest original contribution to the advancement and use of welding

Philadelphia Section Excels

A truly excellent job was done by the members of the Philadelphia Arrangements Committee in the handling of the many details which assured the success of the Meeting. The group included A. M. Garcia, Chairman; B. D. Gates, Vice-Chairman; R. R. Irving, Secretary; E. E. Goehringer, Delaware Valley Products; L. D. T. Berg, Adams National Dinner; C. M. Schaub, Hospitality; R. D. Bradway, Housing; J. E. Norcross, Informal Panel Discussions; D. H. Buerkel, Ladies' Entertainment; F. W. Hussey and J. J. Powers, Jr., Meeting Sessions; F. Iapalucci, Plant Tours; R. D. Thomas, Jr., President's Reception; R. S. Babcock, Publicity; K. W. Ostrom, Signs; R. S. Phair, Technical; R. S. McCracken, Jr.; Ticket Sales; R. Guenzel, Transportation; C. D. Cooper, F. Judelsohn, H. C. Heivly, and A. C. Young, Members-at-Large.

Handling the local arrangements for the AIEE Electric Welding Committee were S. M. Kapell, Chairman; J. H. Beckmann, Hospitality; L. M. Clevenger, Housing; Mrs. W. E. Gittings and Mrs. C. T. Pearce, Ladies' Entertainment; C. Boyer, Plant Tours; M. H. Lerner and J. Gordon, Publicity; J. H. Beckmann, Meeting Sessions. James F. Deffenbaugh, Committee Chairman, was in charge of the over-all AIEE activity.

The 38th Annual Meeting of the AMERICAN WELDING SOCIETY will long be remembered by those who were able to participate. The entire activity was conducted with near perfection, and will provide an extremely high mark for future meetings to surpass.

The 1958 AWS National Spring Meeting will be held in St. Louis, Mo., on April 14–18. See you there!

Presidential Address

By J. J. CHYLE

President, 1956-57, American Welding Society

On the occasion of this great meeting of the AMERICAN WELDING SOCIETY here in Philadelphia—and as the president of your SOCIETY—I bring you greetings.

It is with mixed emotions that I do so. Only a short year ago I had the honor to become your president. It has indeed been an honor, gentlemen, and it has been an experience that I shall always cherish. I have enjoyed every moment of it. Yet my emotions are mixed, because I stand here this morning delivering to you what must be my "swan song" as president of the organization.

Lest you should mourn too quickly, however, let me hasten to add that I expect to be around for quite a few years yet, and I have every intention of participating actively in the affairs of the SOCIETY. Old presidents of the AMERICAN WELDING SOCIETY don't die, you know, they just fade slowly away.

There are many things that I could say to you today. There has been much that has happened in the last year that I could report. Some of our affairs have gone well, and for this we can all be happy. In other areas we have not progressed as far as we would like, and these are matters of concern. But rather than discuss these details—if I may call them that—I would like to talk on a somewhat broader scale.

I would like to make only two points. The first is this: Welding has become an integral part of the American way of life. Secondly, it is our job—much more, it is our duty—to be sure that this art of welding stays abreast of the forward march of America, ready and able to meet the challenges that are before us and those that surely will arise.

Let me take you back more than 35 years to a period just following the end of World War I. It was a simple era. America had not yet become great. Yet the seeds of greatness had been planted, and mighty events were to take place. Many industries stood at the threshold of developments that could scarcely be imagined. There were men of vision who say these things, or suspected them, yet wherever they turned they found themselves hampered and hindered, unable to move forward because of the lack of technological advances.

Let us take one example—that of the oil industry. At the close of World War I, this industry faced serious problems. Gasoline at that time was produced in pressure vessels of riveted design. The yield of gasoline was low and its cost was high. Research developments after the war indicated that this situation could be improved by the introduction of higher pressures and temperatures in the refining process. There were serious limitations to this, however, because pressure vessels of riveted construction leaked at the higher pressures,

Fig. 11 Our Society's Honorary Membership was bestowed upon Past-President O. B. J. Fraser, acknowledging him as a person of outstanding eminence in the profession of welding and one accredited with exceptional accomplishments in the development of the welding art

Fig. 12 The Samuel Wylie Miller Memorial Medal and Certificate, symbolic of meritorious achievement which has contributed conspicuously to the advancement of the art of welding and cutting, was awarded to Fred L. Plummer, AWS past-president

Fig. 13 DeWitt C. Smith was the recipient of the 1957 Adams Lecture Certificate and Honorarium, the annual award given to an outstanding scientist or engineer for his lecture on some new and distinctive development in the field of welding. Left to right are President Chyle, Dr. Smith, First AWS President and Founder C. A. Adams, and President-Elect Sander.

Fig. 14 The reception for President-Elect Sander was an outstanding event. *Everybody* was there and *everybody* had a grand time visiting with friends and being introduced to the incoming, outgoing and participating Societies' officers.

Fig. 15 Naturally we could not resist the call to bring together our elected officers on this unique all-welded staircase with its unusual ornamental back-drop of bronze plates, rods and shapes

From left to right (upward) we have President Chyle, President-Elect Sander, First Vice-President-Elect G. O. Hoglund, Second Vice-President-Elect C. I. MacGuffie, and Treasurer-Elect H. E. Rockefeller.

with resulting hazardous and uncertain conditions.

At this time basic developments in the field of welding were made, resulting in the use of a new covered electrode for arc welding. This made possible the welding of single piece pressure vessels. It is with what I hope is pardonable pride that I tell you that it was my own company that led in this development. In 1925 we produced the first welded pressure vessel for the oil industry, with walls 3 in. thick, designed for pressures from 600 to 900 psi and to be operated at temperatures up to 950° F. The vessel was made for the Texas Co., and I am glad to report that that original all-welded vessel is still in operation at Beaumont, Tex.

This advance in fabricating operations had a tremendous effect in the petroleum industry. The cost of gasoline dropped abruptly. Its quality was improved. In a comparatively short time the consumption of gasoline had increased impressively, with no increase in price.

Let us take another example of how advances in the application of welding techniques made spectacular contributions to America. In the 1920's, large diameter steel pipe could be made only by the laborious method of "working" steel billets around mandrels to produce seamless pipe. It was a slow and costly process. In the late 1920's, for example, all of the pipe mills in the country had a combined capacity of only three miles of pipe per day.

It was known that if pipe could be made rapidly and economically it would be possible to transport petroleum products through pipe lines for hundreds and even thousands of miles at great savings. It would also make possible the distribution of natural gas to all areas of the nation—and natural gas at that time was simply a waste product that had to be flared off at the wells.

A new method of making pipe was devised in 1928. Flat plates were rolled into tubes, and resistance welding was employed to make a 40-ft longitudinal

weld in less than 30 seconds. Within a short time one company was producing 30 miles of such pipe per day, and the cost per mile was less than half of what it previously had been. Here was strong pipe, light, at low cost, and it could be produced fast. In a short time plans came into being for pipe lines of a diameter and length that had never been dreamed of before. Today thousands of miles of pipe line interlace the United States and the great producing fields of the southwest are pouring vast quantities of natural gas into all parts of the country. For instance, these huge lines serve the Chicago Area and they deliver a total of *one billion* cubic feet of gas *per day*. None of this would have been possible had it not been for welding.

These are merely examples to illustrate how welding has played an important and vital part in one basic industry. Much of the same story can be told in the automobile industry, the chemical industry, in the development of aircraft, in the explorations in the field of nuclear energy. Wherever you turn, welding is playing its part.

I could spend a long time this morning telling you of the role that welding played in the winning of World War II and the Korean War—of the vital part it played in the production of ships and bombs, jeeps, transport trucks, all of the vast industrial process, which spelled defeat for the Fascists, the Nazis and the Japanese. And I could go beyond that and tell you the complex part that welding plays in our everyday life, from the moment we get up in the morning until we turn out the last light at night. The food we eat, the clothes we wear, the homes we live in, the cars we drive—in all these and many other things, welding plays its continuing part.

Let me illustrate this further. For the welding industry the dollar volume of sales in 1956 was approximately $850,000,000. This figure breaks down into three principal parts.

Fig. 18 The Adams Dinner was featured by a record attendance and was an outstanding social success

First, about $90,000,000 represents the sale of coated electrodes and wire. In terms of weight this amounts to a production of about 640,000,000 lb of electrodes and wire. Converted into feet, it is a continuous length amounting to 1,500,000 miles of wire, coated and bare, that was used by 350,000 welders.

Secondly, in 1956, there were 72,137 welding machines that were sold for a total value of $20,000,000.

Thirdly, approximately $640,000,000 was spent for welding gases—oxygen, acetylene, argon and helium.

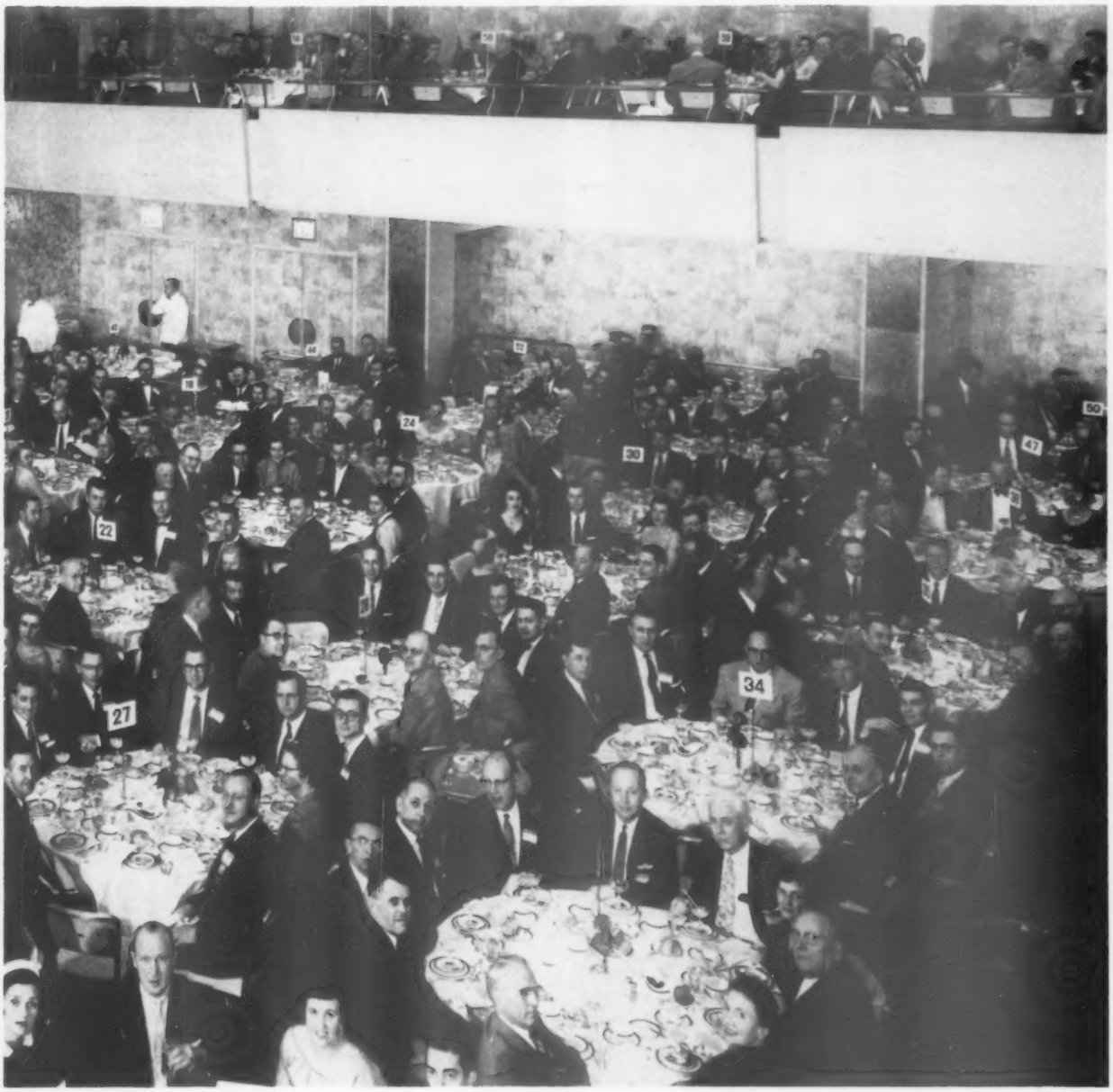
This will give you a general idea of the size of the welding business as it exists now. The really interesting fact, however, is that this three-quarters of a billion dollars makes possible the fabrication of products worth from 50 to 100 times that volume of business. Today, ladies and gentlemen, welding is indeed a part of the American way of life.

Which brings me to my second point—namely, that we as members of this profession, and as members of our SOCIETY, have responsibilities that we must not overlook. We have selfish interests, to be sure. Yet in a far greater sense we have a never-ending job of seeing to it that we maintain the leadership in this field that we have thus far attained. This is not going to be easy.

Take the matter of education. Here is one of the most important areas in which we can insure ourselves against losing that leadership. What are we doing about it? There is only one university in the country today, which is granting a degree in welding engineering, and it annually is producing a mere handful of such men. Yet in Germany there are dozens of universities that are granting such degrees today, and in Russia there are 20 of them. What do you think will be the ultimate result of such a situation if it continues?

Another area of vital importance is that of research. Here the prime responsibility must rest upon industry, as it has in the past. Back in the 1920's, in

as well. It was impossible for the photographer to get everyone into the picture, but—he did his best



the oil industry, it was research that found the answers and broke the bottlenecks. And in all the tremendous strides that have been made since then, in war and in peace, it has been research that has relentlessly searched for the better ways of doing things. Our universities cannot lead in this type of activity, because it is only in industry that we can find the vast resources necessary for such work. Also, in the competitive atmosphere in which industry lives there is found the "inspiration" for continuing programs of research.

Research in itself is not enough, however. One more step is needed, and that is the translation of research into action. This is best accomplished, I think, by a continuous program of education and training within industry. The laboratory must move into the factory: it must demonstrate new techniques, and must teach the production lines how to use them. It is a dynamic challenge to us, one that we must fully face.

And so, ladies and gentlemen, I shall sum up. First, welding has become an intimate part of the American way of life, and, indeed, had a great deal to do with creating it. Secondly, it is imperative that the art of welding continue to march forward. Much of this can be assured if our SOCIETY and we members continually strive for more education, more research and the practical application of the results of both education and research.

And in closing, let me again say to you all that it has been a rare privilege to serve you this year. I shall continue to serve in whatever capacity this SOCIETY may ask. Thank you.

Fig. 16 Fitting to the occasion of the Adams National Meeting, we were honored by the participation of our Society's Founder and First President Doctor Comfort Avery Adams. Here, Harry W. Pierce, AWS past-president, is introducing Mr. and Mrs. R. T. Kenworthy (AWS exposition manager) to Dr. Adams and his charming daughter-in-law, Mrs. Clayton Adams

Fig. 17 Following the breakup of the President's Reception here, we were able to group together the celebrities of the evening.

From left to right (*first row*) they are Second Vice-President-Elect MacGuffie, First Vice-President-Elect Hoglund, Mrs. Chyle, outgoing President Chyle, Dr. Adams, President-Elect Sander, Mrs. Sander, and Treasurer-Elect Rockefeller. (Second row): Outgoing Treasurer R. Donald, Mrs. Donald, AIEE Vice-President Pearce, Mrs. Pearce, Mrs. Clayton Adams, AWS Director-Elect J. F. Deffenbaugh, Mrs. Deffenbaugh, Mrs. Garcia and Philadelphia Section Chairman A. M. Garcia

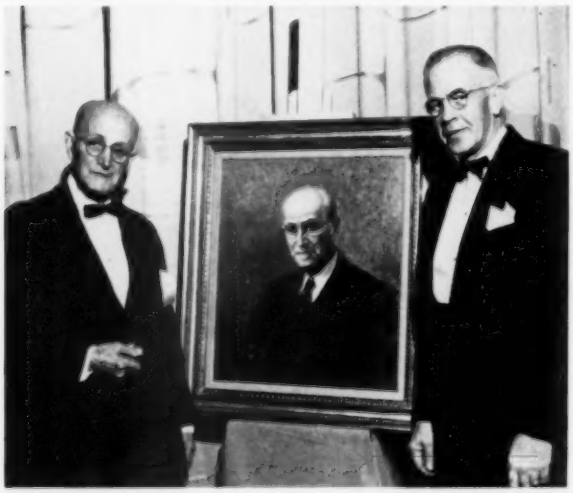


Fig. 19 In his honor, the Society presented to Dr. Adams an oil painting for which he had posed. The portrait was made by the noted Philadelphia artist, Charles Benz. Harry W. Pierce, past-president, after eulogizing Dr. Adams in his talk "Gaslight Through Arclight," made the official presentation of the portrait

Fig. 20 At the Welding Information Conference on Tuesday morning, Second Vice-President-Elect MacGuffie told welding manufacturers how an all-out promotion and publicity program would aid welding and industry

Fig. 21 The camera scope just was not wide enough to include all the authors and sessions chairmen who made their contributions to Tuesday's technical meetings. An Authors' Breakfast such as this was held each morning, Monday through Friday

Fig. 22 All technical meeting sessions at the Sheraton Hotel, as well as the informal Welding Conference at Convention Hall, were well attended as is evident from the above. In all there were 18 technical sessions with a total of 54 papers treating with every phase of welding

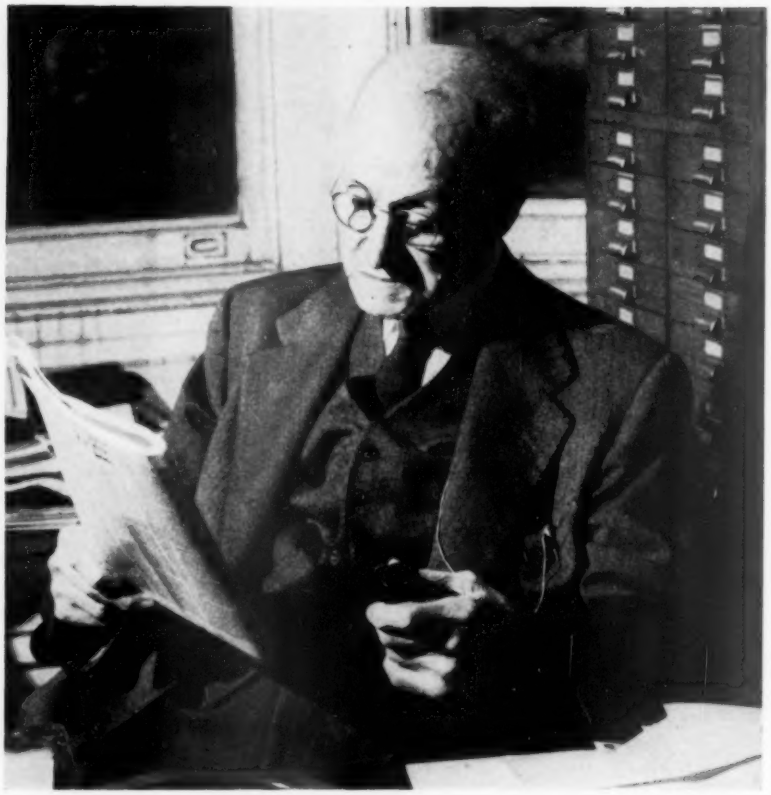
Fig. 23 The Fifth Welding Show opened its doors at Convention Hall at noon on Tuesday, April 9th

The entrance was jammed by attenders waiting to get in. But first the heavy entrance chain had to be severed. President-Elect Sander did not hesitate a minute. Just grabbed the torch, pulled down the eyeshield and sliced it through. Fred L. Stetner, chairman of our San Francisco Section, and the awaiting guests watchfully admire "Sandy's" technique.

Fig. 24 The Fifth Welding Show topped them all for attendance: there were 11,254 visitors; someone from everywhere; every state and from abroad; all anxious to see the very latest in welding

Fig. 25 The aisles of the Fifth Welding Show were never empty; not for one moment. Someone going, someone coming; someone asking; someone seeking. And all who came saw, got their answers and left with the satisfaction that welding was not only here to stay but was a vibrant, growing asset to the life of American industry. Plus-quoting P. T. Barnum, it was "the greatest *welding* show on earth"!

A Grand Young Man



Comfort Avery Adams

A "grand young man," Comfort Avery Adams, who celebrated his 88th birthday last November 1st, was honored at the 1957 Adams National Meeting of the AMERICAN WELDING SOCIETY in Philadelphia during the week of April 7th. Young and old came from every corner of the United States to pay homage to the founder of our SOCIETY and to participate in the technical and social affairs.

At the dinner on Monday, April 8th, Dr. Adams was presented with an oil painting of himself. His career and accomplishments were traced by another past-president of the SOCIETY, Harry W. Pierce.

A native of Cleveland, Dr. Adams obtained his education at Case School of Applied Science, graduating in 1890 as a Bachelor of Science in Mechanical Engineering. From 1886 to 1890, throughout his undergraduate period, he was laboratory assistant to the great physicist, Dr. Albert A. Michelson, the inventor of the interferometer. He helped build the large interferometer employed in the Michelson-Morley experiment on ether drift. This resulted in the abandoning of the old hypothesis that light was transmitted through space by the aid of what was then called "luminiferous ether." The new finding was one of the foundation stones of the first Einstein Theory of Relativity. The optical system of this interferometer was on the surface of a granite block about two foot square and one foot thick floating in mercury. In an auxiliary experiment, the bending of this block, due to a silver dollar placed in the center of the surface, was accurately measured.

From 1890 to 1891, Dr. Adams had two jobs. For the first six months, he

Very few persons have lived a life as full as that of Dr. Adams

In 1890 he was one of a distinguished group of young men who travelled to latitude 55°, Alaska, for the purpose of studying and reporting on Glacier Bay and its glaciers. This intrepid team brought forth an early reliable report on measurements made on the site of the movement of glacier ice. Their findings resulted in the correction of an erroneous estimated movement of 70 ft per day to a recorded movement of 7 ft per day. Pictured above is the Adams Glacier, named after our Founder, a tributary glacier with moraines in the foreground.

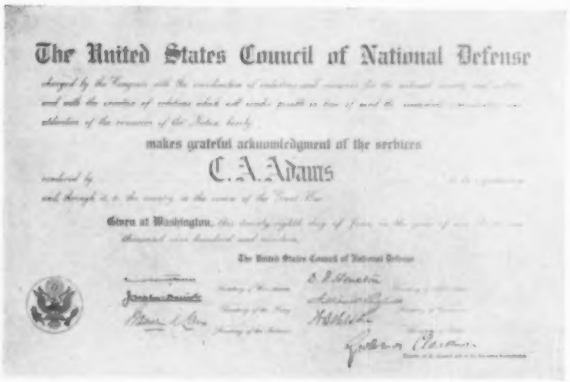
Protection against the elements on the Glacier Expedition was provided the group by their own hand-built shanty

The stones and rocks brought down by the glaciers to the moraines were fashioned into a rough but stout chimney. Taking a hard-earned rest after its completion are Dr. Adams (in white cap, in the center of the group) and the other members of the team.

Our Founder was a native of Cleveland

He graduated from Case School of Applied Science in 1890 with the degree of Bachelor of Science in Mechanical Engineering. From 1886 to 1890, during his undergraduate period, he was laboratory assistant to the great physicist, Dr. Albert A. Michelson. Here we see Dr. Adams *(extreme left, first row)* on the day of his graduation.

In 1894 the Universal Exposition at St. Louis, in commemorating the acquisition of the Louisiana Territory, gave a Commemoration Diploma to Dr. Adams who served as a Member, International Group Jury of Awards in Electricity Department



The United States Council of National Defense

makes grateful acknowledgment of the services

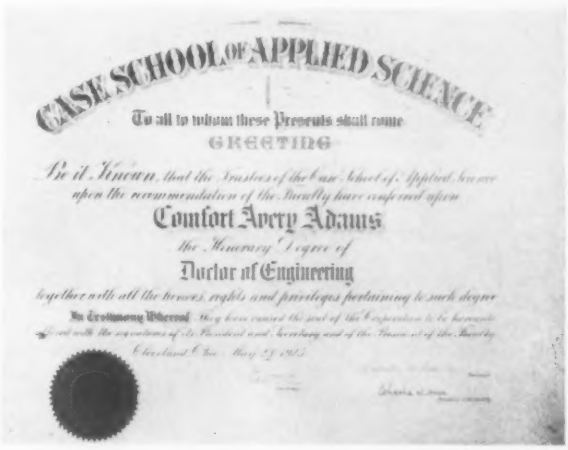
rendered by C. A. Adams

Given at Washington

The United States Council of National Defense

On June 28, 1919, the United States Council of National Defense made grateful acknowledgment of the services rendered by Dr. Adams to his country during the Great War

The acknowledgment was signed by the Secretaries of War, of Navy, of Interior, of Agriculture, of Commerce, and of Labor as well as by the Director of the Council and of the Advisory Commission.



CASE SCHOOL OF APPLIED SCIENCE

To all to whom these Presents shall come

GREETING

Be it Known, that the Trustees of the Case School of Applied Science upon the recommendation of the Faculty have conferred upon

Comfort Avery Adams

the Honorary Degree of

Doctor of Engineering

together with all the honors, rights and privileges pertaining to such degree

In Testimony Whereof

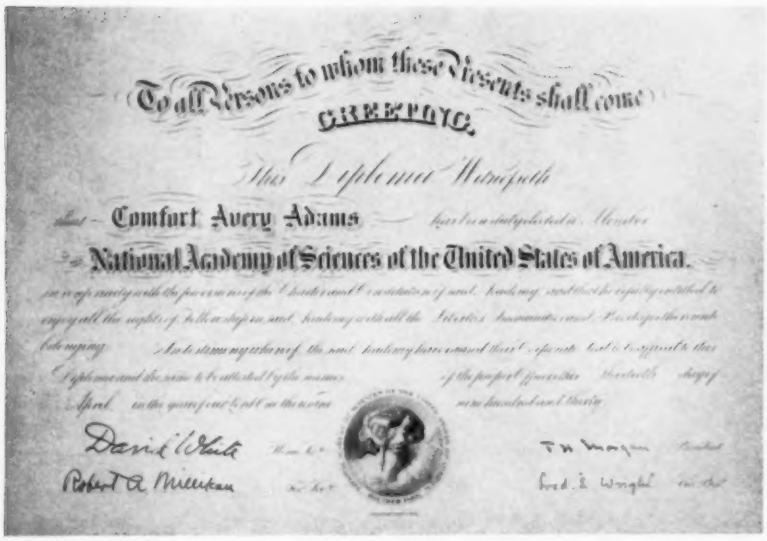
On May 28, 1925, the Honorary Degree of Doctor of Engineering was conferred upon our first president by the Case School of Applied Science

was assistant to the chief engineer of the Brown Hoisting and Conveying Machine Co. of Cleveland, and assisted in the design of two cantilever cranes, for the Newport News Shipbuilding Co., which were in successful operation for many years thereafter. During the last half of this year, he was engineer for the Brush Electric Co. of Cleveland where he designed two large d-c generators for the Rochester Electric Light Co. and participated in the design of the first gearless traction motor.

In September 1891, Dr. Adams was appointed instructor in electrical engineering at the Lawrence Science School of Harvard University. From 1896 to 1905, he was assistant professor of electrical engineering and from 1906 on he was professor of electrical engineering. In 1914 he was appointed the Abbot and James Lawrence Professor of Engineering. He was the first professor to bear the Lawrence title. In 1936 he was given the additional title of "Gordon McKay Professor of Electrical Engineering." His present Emeritus title covers both of these professorships up to 1936, when he retired from Harvard at the age of 68.

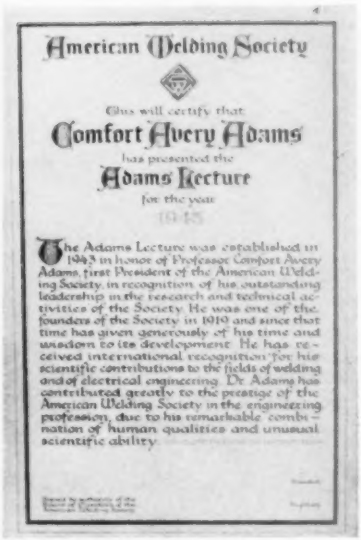
Although he was Dean of the Harvard Engineering School in 1919, his extracurricular activities as president of the AIEE, as president of the AMERICAN WELDING SOCIETY, and as chairman of the Engineering Division of the National Research Council, together with his consulting work, resulted in his resignation as Dean, in order to avoid sacrificing his teaching work.

Dr. Adams' consulting work covers forty-five years for the Okonite Co., fifteen years for the General Electric Co., thirty years for the Babcock and Wilcox Co., fifteen years for the Budd Co., ten years for the Warner Sugar Refining Co., two years for the American Sugar Refining Co., eleven years for the American Tool and Machine Co. and with numerous other companies for shorter durations. He also served as



To all Persons to whom these Presents shall come
GREETING:
Comfort Avery Adams
National Academy of Sciences of the United States of America.

Membership in the National Academy of Sciences of the United States of America was bestowed upon our Founder on April 30, 1930



American Welding Society

This will certify that

Comfort Avery Adams

has presented the

Adams Lecture

for the year

The Adams Lecture was established in 1943 in honor of Professor Comfort Avery Adams, first President of the American Welding Society, in recognition of his outstanding leadership in the research and technical activities of the Society. He was one of the founders of the Society in 1919 and since that time has given generously of his time and wisdom to its development. He has received international recognition for his scientific contributions to the fields of welding and of electrical engineering. Dr. Adams has contributed greatly to the prestige of the American Welding Society in the engineering profession, due to his remarkable combination of human qualities and unusual scientific ability.

Dr. Adams presented the first Adams Lecture in 1943

In his honor this lectureship has been perpetuated by our Society. The Award is made annually to an outstanding scientist or engineer for a lecture presenting some new and distinctive development in the field of welding.

expert in a number of law suits, including several of the largest gas explosions in this country, in all of which he was on the winning side.

Although Dr. Adams has made history in a number of branches of science and engineering, space only permits to briefly trace his imprint on two branches —namely electrical and welding engineering.

In 1900 and succeeding years through 1956, Dr. Adams presented papers on alternator regulation, synchronous, induction, centrifugal and repulsion motors, high-frequency induction furnaces and many other branches of electrical engineering. He pioneered not only in the design of electrical machinery but also in high-voltage electric cables. Specification in this field gave cognizance to the result of his careful studies.

Dr. Adams has been accorded many honors. Among these are two honorary degrees of Doctor of Engineering.

In 1929 he was the first recipient of the Miller Medal from the AMERICAN WELDING SOCIETY and shortly thereafter was made an honorary member of the SOCIETY.

In 1940 he received the Lamme Medal of the AIEE, "For his contributions to the theory and design of a-c machinery and his work in the field of electric welding."

In 1956 he was awarded the Edison Medal of the AIEE which is the highest award given by that Society. The citation follows: "For pioneering achievements in the development of alternating current electric machinery and in electric welding; for vision and initiative in the formation of an engineering standards organization; and for eminence as an educator and consulting engineer."

His work in the electrical field led him not only to the welding field, but to closely allied fields of research and standardization. He helped found the American Standards Assn., serving as its first chairman. Also, he served as chairman of the AIEE Standards Committee. His chairmanship of the Engineering Division of the National Research Council in 1919–21 led to organizations such as the "Conference on Electrical Insulation" and the "Highway Research Board," both of which are still in existence and doing excellent work.

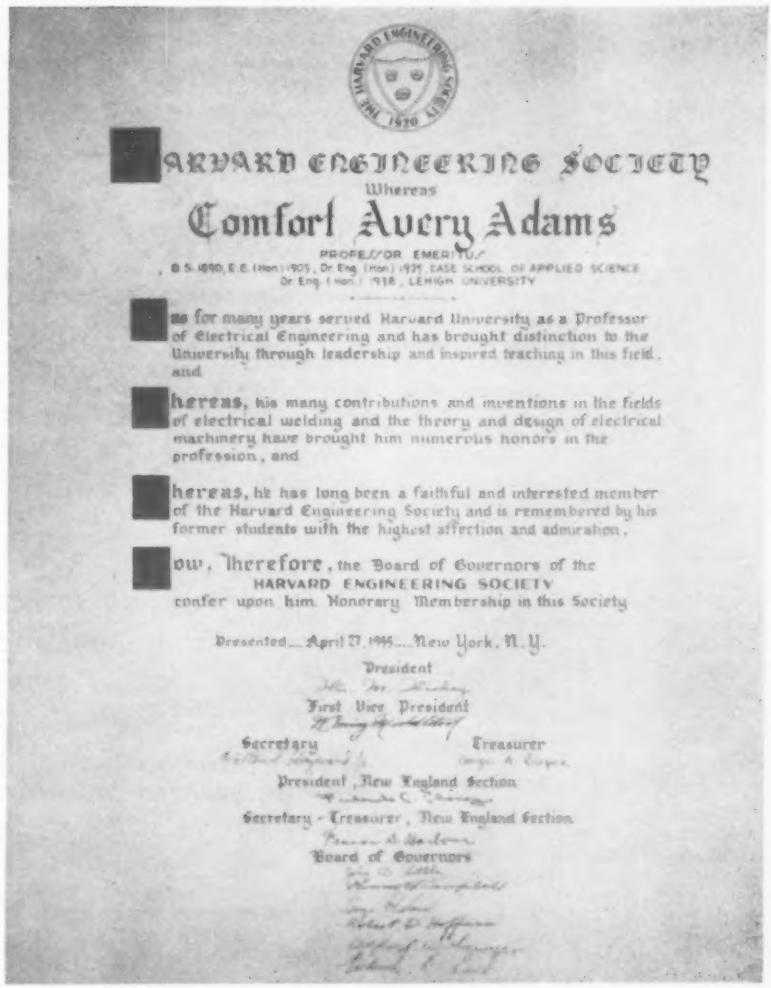
We in the AMERICAN WELDING SOCIETY revere Dr. Adams for his work in welding. It all started in World War I when he served as chairman of the Welding Committee of the Emergency Fleet Corp. which was given the project of applying welding to the building of ships. The work of this Committee was perpetrated by the organization of the AMERICAN WELDING SOCIETY in April 1919. The research work of a subcommittee of the Emergency Fleet Corp. was revived in the organization, in 1920, of the American Bureau of Welding as a joint instrumentality of the AMERICAN WELDING SOCIETY and the National Research Council. Dr. Adams was the first president of the SOCIETY and the first chairman of the American Bureau of Welding.

Later on, in 1935, he was the organizer and first chairman of the Welding Research Council, of which he is still honorary chairman. The Adams Lecture series was established in his name and he gave the first Adams Lecture. Dr. Adams, as previously mentioned,

Ever active throughout his entire life, Dr. Adams never fails to relax and play when the opportunity affords

This is a picture of one of those moments; on the green at the Okonite Golf Tournament at the Rockland County Country Club, June 30, 1953. We will bet he made it, too. See that grin of confidence!

In honor of the many years Dr. Adams served Harvard University as a Professor of Electrical Engineering, and for his contributions and inventions in the fields of electrical welding and theory and design of electrical machinery, the Harvard Engineering Society bestowed Honorary Membership upon him on April 27, 1955



HARVARD ENGINEERING SOCIETY

Whereas

Comfort Avery Adams

PROFESSOR EMERITUS

B.S. 1890, E.E. (Hon.) 1905, Dr. Eng. (Hon.) 1925, CASE SCHOOL OF APPLIED SCIENCE
Dr. Eng. (Hon.) 1938, LEHIGH UNIVERSITY

he for many years served Harvard University as a Professor of Electrical Engineering and has brought distinction to the University through leadership and inspired teaching in this field, and

hereas, his many contributions and inventions in the fields of electrical welding and the theory and design of electrical machinery have brought him numerous honors in the profession, and

hereas, he has long been a faithful and interested member of the Harvard Engineering Society and is remembered by his former students with the highest affection and admiration,

ow, therefore, the Board of Governors of the HARVARD ENGINEERING SOCIETY confer upon him Honorary Membership in this Society

Presented April 27, 1955 New York, N. Y.

President

First Vice President

Secretary Treasurer

President, New England Section

Secretary - Treasurer, New England Section

Board of Governors

also received awards of honorary membership and the Miller Medal from the SOCIETY. He is an honorary member of its Board of Directors.

Another society profited by his organizational and standardization experience, namely, the Boiler Code Committee of the ASME, of which he was an active member for two decades and is now an honorary member. He helped bring about the code rules relating to welding of pressure vessels and boilers.

Although the above represents only a small percentage of the scientific and engineering subjects which attracted the attention of the founder of the AMERICAN WELDING SOCIETY, it is sufficient to recognize his stature as a scientist and engineer.

The man, Dr. Comfort A. Adams, will long live in the hearts of those who know him, for two other reasons—his roles as a great humanitarian and as an educator. We must pass lightly over the humanitarian side, as it is personal to him and the friends that he helped, the causes he supported and the several boys who owe their college education to his generosity.

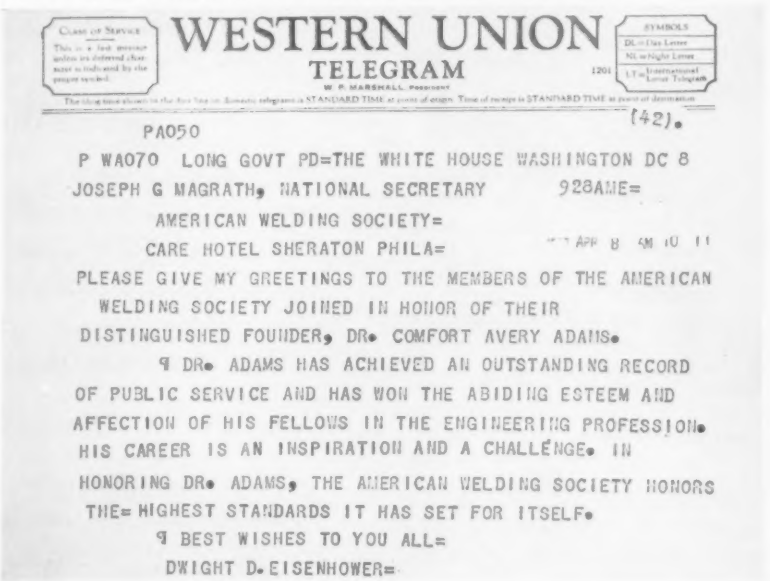
We may, however, dwell a lot more extensively on his role as an "educator." Those who were fortunate to know him in this endeavor, and the number is legion, have permanently profited by this training. This group includes not only his students at Harvard over a 45 year period, but also members of committees on which he served, and the staffs of the corporations on which he acted as consulting engineer.

He believes that the habit of thinking for oneself is essential, rather than the blind acceptance of prevailing traditions or theories which sometimes are based on unsound premises. He teaches those who come in contact with him to search for the facts and the underlying reasons of why these facts are so.

Always interested, always alert, always searching, and always a kindly smile—all spell Dr. Adams, our "grand young man."

Dr. Adams—we salute you!

On the occasion of the Adams National Meeting in Philadelphia, April 8 to 12, 1957, a very high honor was accorded our Society and its first president and founder by the President of the United States Dwight D. Eisenhower



WESTERN UNION

TELEGRAM

(42).

PA050

P WA070 LONG GOVT PD=THE WHITE HOUSE WASHINGTON DC 8

JOSEPH G MAGRATH, NATIONAL SECRETARY 928AME=

AMERICAN WELDING SOCIETY=

CARE HOTEL SHERATON PHILA= APR 8 AM 10 11

PLEASE GIVE MY GREETINGS TO THE MEMBERS OF THE AMERICAN WELDING SOCIETY JOINED IN HONOR OF THEIR DISTINGUISHED FOUNDER, DR. COMFORT AVERY ADAMS.

¶ DR. ADAMS HAS ACHIEVED AN OUTSTANDING RECORD OF PUBLIC SERVICE AND HAS WON THE ABIDING ESTEEM AND AFFECTION OF HIS FELLOWS IN THE ENGINEERING PROFESSION. HIS CAREER IS AN INSPIRATION AND A CHALLENGE. IN HONORING DR. ADAMS, THE AMERICAN WELDING SOCIETY HONORS THE= HIGHEST STANDARDS IT HAS SET FOR ITSELF.

¶ BEST WISHES TO YOU ALL=

DWIGHT D. EISENHOWER=

Educational Course on Arc Welding Sponsored in Buffalo

An educational course on automatic and semiautomatic arc welding was recently sponsored by the Niagara Frontier Section. The lectures were held at the University of Buffalo on the evenings of March 5th, 12th, 19th and 26th.

The course had two objectives: (1) for those now using automatic processes, to review present practice and provide an opportunity for discussing problems, and (2) for those thinking about starting automatic welding, to assist in selecting the process best suited to do the job. It was developed in line with the thinking of the AWS National Educational Committee, with very gratifying results. Some 180 members and guests registered for the course.

The details of the course were as follows:

Lecture 1. Automatic Welding Applications and Processes—General Introduction and Fundamentals. *Speaker:* Clarence E. Jackson, Linde Company.

Lecture 2. Nonconsumable-Electrode Processes—Tungsten with Argon, Helium, and Other Gases. *Speaker:* Harry D. Mann, Air Reduction Sales Co.

Lecture 3. Consumable-Electrode Processes Without Flux—Argon, Helium, CO_2. *Speaker:* Knut Lindquist, General Electric Co.

Lecture 4. Submerged-Arc Process. *Speaker:* Robert W. Wilson, The Lincoln Electric Co.

Plans are now being considered by the Niagara Frontier Section for additional programs to be held next Fall and Winter.

Erie Forge and Steel Becomes Sustaining Member

Erie Forge & Steel Corp. of Erie, Pa., recently became a Sustaining Member of the AMERICAN WELDING SOCIETY.

Steel forgings and castings for a wide diversity of industries have been the business of Erie Forge & Steel Corp. since 1872.

Today modern equipment is housed in the East and West Works, covering 113 acres. Here, steel forgings are produced from ingots up to 90 in. in diameter, weighing 240,000 lb. One piece steel castings, as heavy as 400,000 lb, and as small as 10 lb, are made in the foundries, and machined in shops which are over a quarter mile long.

Among the Corporation's many products are steel forgings for turbine and generator rotor shafts, diesel engine crankshafts, ship shafting, ordnance, extrusion and other types of presses and steam hammers, and steel castings for rolling mills, hydraulic presses, hydro-electric engines, turbines, cement mills and crushers.

Erie also supplies ingots and blooms to the industry.

The Sustaining Member representative is S. E. Danner.

More Supporting Company Members for AWS

Supporting Company Member enrollment applications have been received recently from five additional organizations:

Burdett Oxygen Co., P. O. Box 508, Norristown, Pa.

Dow Corning Corp., P. O. Box 592, Midland, Mich.

Greenville Steel Car Co., Union St., Greenville, Pa.

Superior Coach Corp., E. Kibby St., Lima, Ohio.

Weimer Welding & Cutting Co., 1041 N. 4th St., Milwaukee, Wis.

All of these enrollments became effective on May 1st.

Sustaining Membership Assumed by Arvin Industries

One of the latest additions to the rapidly expanding list of sustaining members is Arvin Industries, Inc.

This company, with general offices in Columbus, Ind., and with 15 manufacturing plants in south central Indiana, manufactures automotive parts and equipment for all the leading motor car companies of the nation. Also produced are radios, electric appliances, automobile heaters, metal furniture, ironing tables, outdoor barbecue grills and plastic-on-metal laminates.

W. G. Morgan has been appointed Sustaining Member representative.

Special Bulletin!

Effective May 31st, Joseph G. Magrath relinquished his position as National Secretary of the American Welding Society. His resignation has been accepted with deep regret.

We are happy to announce that Fred L. Plummer has been appointed as the new Secretary. Full details will appear in the July issue of the Journal.

A. W. S. Board of Directors

AWS DIRECTORS-AT-LARGE

Term Expires	1957	1958	1959
	R. W. Clark	F. H. Dill	J. H. Blankenbuehler
	J. W. Mortimer	E. D. Peters	G. E. Linnert
	Hal Savage	J. L. Wilson	Gordon Parks
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Junior Past-President	C. H. Jennings	Junior Past-President	J. H. Humberstone

EAC DOINGS

Educational Activities Committee Reports Progress

The Educational Activities Committee presented two items of particular interest to the field of educators during the annual meeting in Philadelphia.

Two educational lectures on the "Significance of Notch Ductility to Weldability and Design of Welded Structures" were given by William Pellini of the Naval Research Laboratory. Mr. Pellini reviewed the developments of the basic principles of weld-metal notch ductility and covered the weldability of structural materials and practical design aspects based on investigations related to ships and other large structures. Both sessions were well attended with standing room only.

The Convention Committee of the AMERICAN WELDING SOCIETY also set aside the afternoon of April 10, 1957, for a symposium on education. A report was given to the group as to what is being done and what is needed in the various fields of education for welding. It was pointed out that approximately 85 members of the SOCIETY are now actively taking part in the various tasks of the Educational Activities Committee. Forty-eight sections of the AMERICAN WELDING SOCIETY have appointed educational liaison representatives in order to assist in an over-all program beginning, where it must, at the section level.

The committee on in-plant training has been organized and is actively studying proposed plans and collecting the material now available in order to determine the new materials which are necessary. Initial effort in the committee on college training has been diligently aimed at increasing the number of universities offering courses with an accredited curriculum in welding. The efforts of this year by the committee on apprentice training have resulted in the beginning of an active training program which should aid in providing some of the trained manpower needed in our expanding field of welding. The visual aids group has under way an up-to-date review in order to compile a complete catalog of the films pertaining to the welding field.

The keynote address of the Symposium on Education was given by Dr. H. L. Bevis, Chairman, National Committee for the Development of Scientists and Engineers. Dr. Bevis called upon U. S. industries to help establish the "respectability of brainpower" among the Nation's young people. Dr. Bevis, who is President-Emeritus of Ohio State University, pointed out that, if the Nation is to meet growing requirements for scientific manpower, a major task is the identification and motivation at an early age of young people with talent for science and engineering.

In discussing welding at the apprentice level, M. M. Hanson, U. S. Department of Labor Bureau of Apprenticeship, showed that welding has become a tool in many of the trades and that apprentice training in such fields as pipefitting, automotive mechanics, structural steel fabrication, and others includes welding. The extensive training in welding which is part of the course for each of these fields was pointed out.

H. E. Baldwin, LeTourneau-Westinghouse Co., discussed education for welding from the supervisor level and emphasized the importance of management also being informed of the possibilities of building with welding.

R. B. McCauley, Ohio State University, emphasized the growing need for engineers trained specifically in welding. The need for engineers with a broad training is essential for the best application of welding.

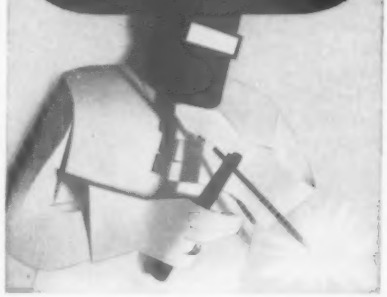
The success of these presentations confirm the growing active interest which has been noted in the field of education for welding.

JOIN NOW!

If you are interested in better welding, lower fabrication costs and increased productivity, you will gain from investment in AWS Membership. You can learn how to join by writing AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, N. Y.

Every Welding Operator should have the opportunity of trying this new

HOBART 413 ELECTRODE!



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Section News and Events

as reported to Catherine O'Leary

PLANT TOUR

Fort Wayne, Ind.—The *Anthony Wayne* Section was invited by the Fruehauf Trailer Co., Inc., to tour their plant at Fort Wayne on April 25th.

Mr. McFarland, plant manager, welcomed the 32 members of the Section and described, in general, the type of trailers made there. After the welcoming address, the company served lunch and also gave everyone a plastic briefcase containing brochures on their trailers.

The plant tour followed the luncheon and took about two hours to see just those items pertaining to welding. A very interesting afternoon was spent thanks to the hospitality of the hosts.

WELD DESIGN

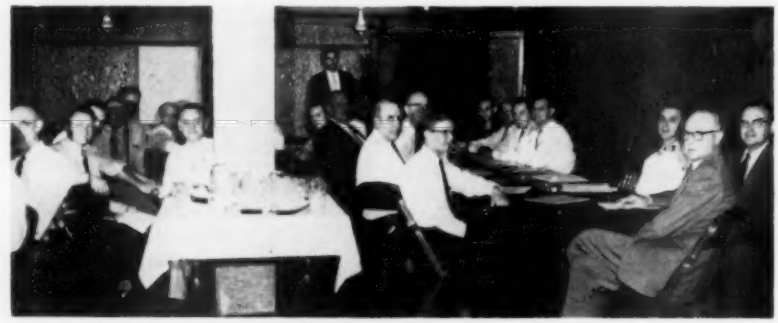
Birmingham, Ala.—The last dinner meeting of the current season was held on April 9th by the *Birmingham* Section at Gulas Restaurant with 35 members and guests present.

The speaker was John E. Durstine AWS, district sales manager, Lincoln Electric Co. His subject, "The Use of Polarized Light Models in the Study of Weld Design," was illustrated with slides.

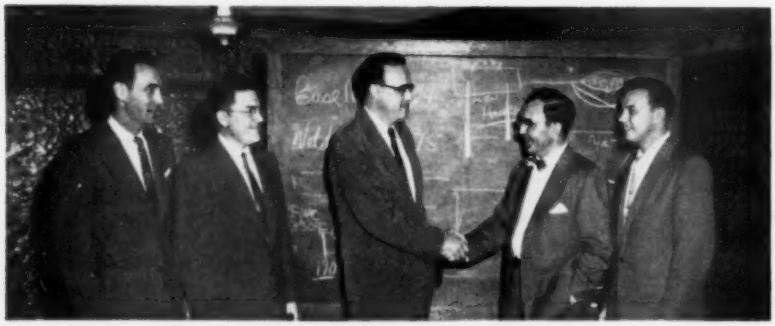
With this method of presentation, the actual strain pattern that develops in various shape welds and around various types of welds was visible. By this method of study, it was shown that it is possible to design a welded joint and place the metal where it is needed, thereby getting maximum strength at minimum cost. The mistakes of overwelding were emphasized and a full explanation was given of where metal should be placed to carry the load of the structure.

This was a very timely subject and was well presented by Mr. Durstine.

DAYTON SECTION HOLDS DESIGN CLINIC



Part of the 34 members and guests who attended the "Welding Design Clinic" sponsored by Dayton Section on April 23rd



G. O. Williams, chairman of Welding Design Clinic Committee of Dayton Section, congratulates Prof. Roy B. McCauley on the success of the Clinic. Left to right: J. H. Headapohl, C. D. Schultheis, Mr. Williams, Professor McCauley and William L. Green

PLANT TOUR

Groton, Conn.—On April 18th, the *Bridgeport* Section and the *Worcester* Section were invited by the *Hartford* Section to join them in their annual plant tour. The tour was made of the Electric Boat Division of General Dynamics Corp. at Groton, Conn. The Electric Boat Division, one of the argest private builders of submarines, has three nuclear powered subs on the ways at the present time. The tour, which was a tremendous success, took in all the principal developments where the welding of huge units and their components which go into the final assembly were seen.

The tour which started at 1:30 P.M. was followed by a delicious steak dinner and cocktails at the "Meadows" in New London. Total attendance at the tour and dinner were 215 members and guests. An extremely enjoyable day was had by all.

STUD WELDING

Whiting, Ind.—The annual Calumet region dinner meeting of the *Chicago* Section was held on March 22nd in the pleasant surroundings of Vogel's Restaurant in Whiting, Ind. Here, members and guests were entertained by a premeeting talk and the showing of slides of the country of Burma, its people, customs, trend and geography by C. E. Barthel, Jr., assistant director of Armour Research Foundation.

The technical speaker was R. C.

OVER

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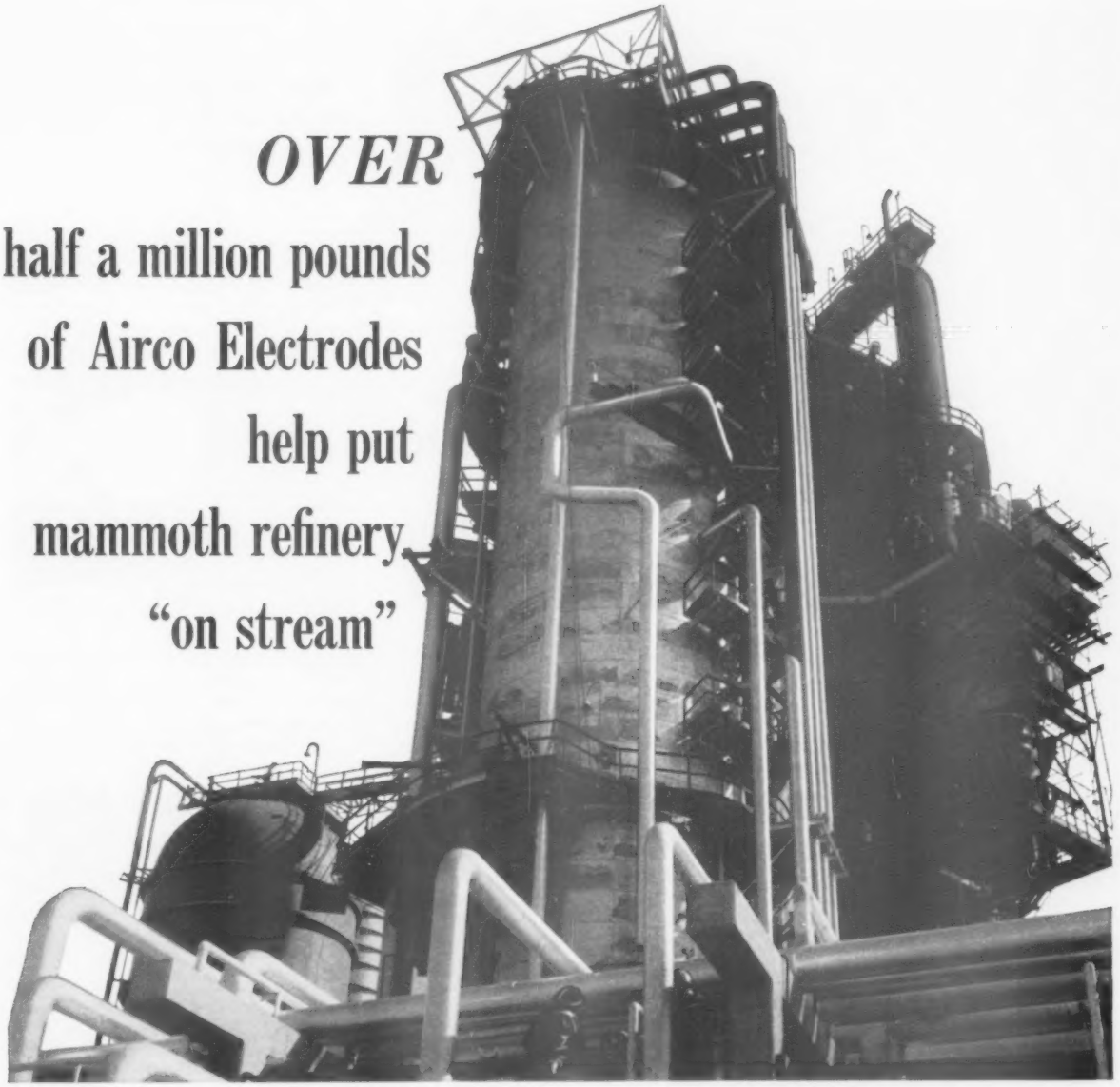

View of the world's largest "cat cracker" processing 102,000 barrels of oil per day.

The Tidewater Delaware Refinery is the largest plant of its kind ever built at one time. An indication of its size is that each barrel of crude oil or partly processed liquid travels through nearly 250 miles of installed piping by the time it reaches the gigantic product storage tanks.

Welding played a vital role in almost every phase of construction, and the products and services of Airco were used extensively to meet the volume requirements. Over half a million pounds of Airco electrodes of every type were employed on the job.

In building a refinery—or, repairing any small part—Airco's Electrode Pocket Guide can help you select the best electrode for the job. Its 48 illustrated pages provide complete information, graphs and charts, applications and procedures, for using the complete line of Airco Electrodes.

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Part of large group in attendance at April 19th meeting of Detroit Section

"QUIZ THE EXPERTS" NIGHT HELD BY DETROIT SECTION

Shown below are the "experts" of the competing teams from the Indiana, Anthony Wayne, Toledo and Detroit Sections

Captain J. R. Wirt of the victorious Indiana Section receiving the trophy from Captain Harry M. Johnson of Anthony Wayne Section, last year's winner

Singleton AWS, manager of industrial sales, Nelson Stud Welding Division, Gregory Industries, Inc.

Mr. Singleton's subject, dealing with stud welding, covered all phases of welding principles, application, operation, usage, inspection and trouble shooting in the use of steel studs. His talk was accompanied by slides showing various applications when used in highway, bridge and building construction. Of particular interest was the application of studs for use in securing concrete road beds to bridges in the as-cast form. This revolutionary application alone has reflected a considerable saving in man-hours and money in the road-building trade.

The meeting was attended by a group of approximately 125 persons who, to say the least, had a very informative and enjoyable evening.

ARC WELDING

Cincinnati, Ohio.—Sixty members and guests of the *Cincinnati* Section were present at the regular monthly dinner meeting held on April 23rd in the Engineering Society of Cincinnati. Speaker was Ralph Trentham AWS of the Linde Air Products Co., Indianapolis, Ind. His subject was "Magnetic-Flux Gas-Shielded Arc Welding."

Mr. Trentham's talk covered the newest shielded-arc process developed by Linde. It makes use of a continuously-fed wire electrode that is magnetically coated with flux and shielded in a gas atmosphere. It can be used in all positions at greater speeds than covered electrodes. A specially compounded magnetizable flux is placed in a dispenser and fed from this point through a flexible tube to the torch. The dispenser is designed to measure exactly the amount of flux in proportion to the amount of wire being fed. Normally a half pound of flux is used per pound of wire. The flux is fluidized at the dispenser and in a stream of welding grade CO_2 gas. At the torch nozzle the magnetic field created by the electric current passing through the wire, magnetizes and attracts the flux to the wire. The flux and the shield gas stabilize the arc, protect the puddle from atmospheric contamination, refine the metal by deoxidation and regulate the coding rate by their blanketing and insulating action.

Rate of deposition is reported to be 50 to 100% greater than with covered electrodes. High-strength welds were reported with 25–35% elongation and 60–70% reduction of area with A212 steel.

LOW-ALLOY STEELS

Denver, Colo.—Twenty-four members and guests of the *Colorado* Section were present at a dinner meeting held in the Dutch Room of the Adams Hotel on April 8th.

John R. Zadra, assistant superintendent of Quality Control Development, Colorado Fuel and Iron Corp., addressed the group on the subject of "The Production of Welding Quality Carbon and Low-Alloy Steels." Mr. Zadra has been with his company for 21 years and is well versed in his subject. His talk proved very interesting and instructive. He also invited the section to visit the plant at Pueblo. It is likely that this invitation will be accepted at a later date.

WELDING DESIGN CLINIC

Dayton, Ohio.—The *Dayton* Section held a one day Welding Design Clinic on April 23rd, at the Dayton Engineers Club, Dayton, Ohio.

This year's clinic, conducted by Roy D. McCauley, professor and chairman, and William L. Green, instructor, Department of Welding Engineering, The Ohio State University, was a continuation of a program set up by the Dayton Section some 3 years ago. The primary emphasis of the clinic is placed on basic engineering thinking and data behind welded design. It is felt that, in the field, this phase of welding education is neglected. Education on detailed practical applications is well covered in the trade papers, AWS technical programs and publications furnished by manufacturers of equipment and supplies.

Topics covered were "Engineering Concept of a Weld," "Fundamentals of Machine Design," "Redesign of Machine Frames and Components for Welding" and "Recent Developments in the Welding Field."

Members of the Welding Design Clinic Committee for the Dayton Section are G. O. Williams, chairman, and J. H. Headapohl of Hobart Bros. Co. and C. D. Schultheis of Frigidaire Division of General Motors Corp.

QUIZ THE EXPERTS

Detroit, Mich.—The regular monthly meeting of the *Detroit* Section was held at the Engineering Society of Detroit on April 19th at 6:15 P.M. for dinner and at 8:00 P.M. for the regular yearly "Quiz the Experts" meeting. The dinner was well attended to see and hear Thor Johnson of Sun Oil Co. with his Magic Barrel. Mr. Johnson held the group's close attention.

The "Quiz the Experts" panel of experts did a very commendable job in answering all questions, and the team with the highest score took the Detroit Section "Intersectional Contest Trophy" home with them. The trophy was first won in 1950 by the Detroit Section and since has made the rounds. This year it was won by the *Indiana* Section: J. R. Wirt, captain, Frank Schaefer, E. F. Holt, Ralph Trentham and Carl Sauer.

The defending team—*Anthony Wayne* Section—consisted of Capt. Harry M. Johnson, James McClain, George Laws and K. H. Zimmerman.

The other competing teams were: *Toledo* Section; Captain Tom Ellis, Oran Fisher, Jim Sapp and Walter Schmidt; *Detroit* Section; Captain Doug Harvey, Jim Morrisey, Jim Larimer, and Tom Shearer.

PLANT VISIT HELD BY LONG BEACH SECTION

Members and guests of the Long Beach Section shown on the occasion of their visit to the Research Welding & Engineering Corp. plant in Compton, Calif.

Roy Clark acted as moderator and was very ably assisted by Judges John Kotchian, Len Broniak, Bob Barley and Ernie Keifer.

FLAME STRAIGHTENING

Cumberland, Ind.—About 60 members and guests of the *Indiana* Section were present for an excellent dinner and meeting held on February 22nd at Buckley's Restaurant in Cumberland.

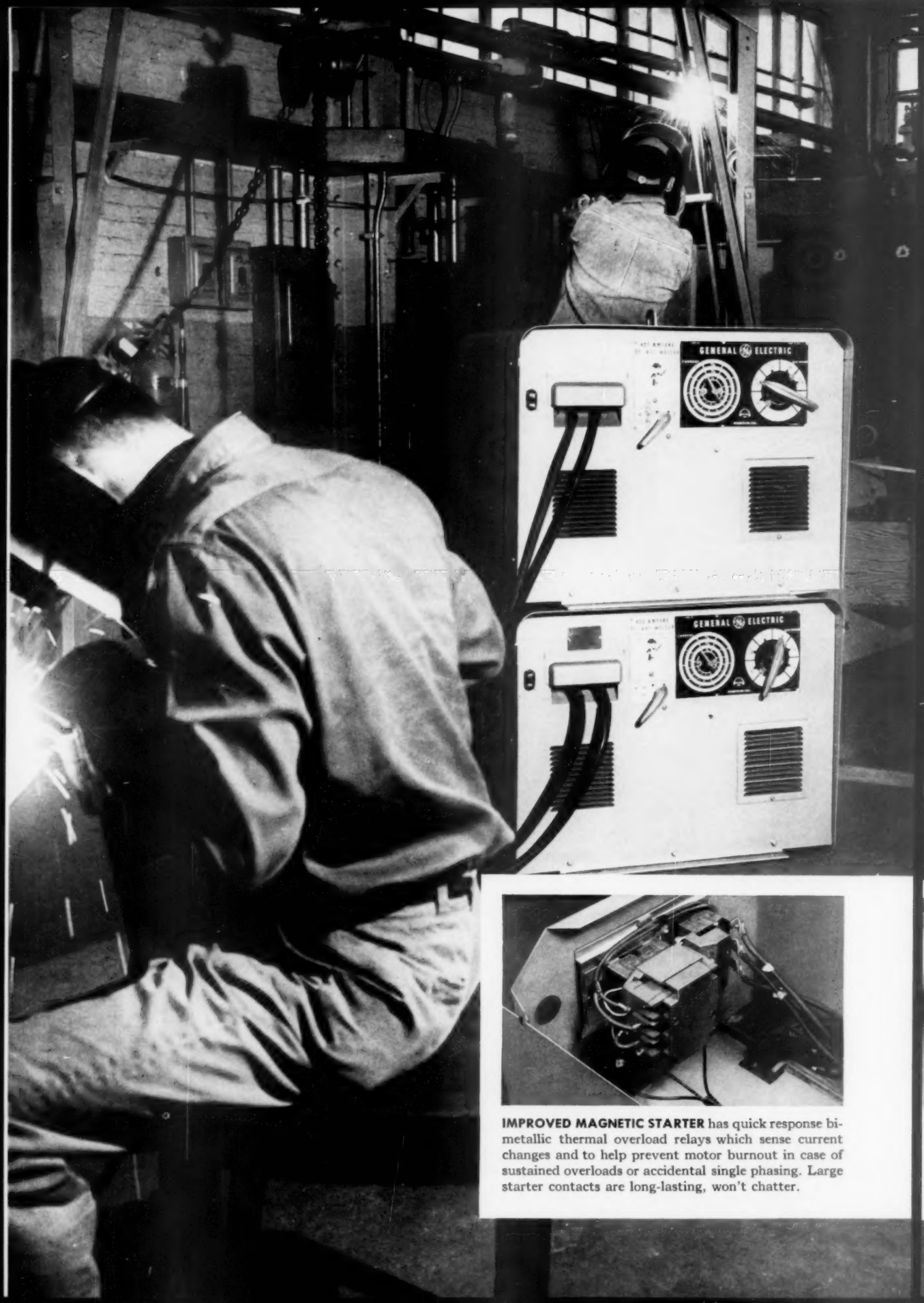
Guest speaker was J. R. Stitt AWS of R. C. Mahon Co., Detroit, Mich. The subject was "Flame Straightening" and was illustrated with slides. It was shown how the ingenious use of flame straightening was used successfully in both the construction and

Guest speaker Russell Meredith addressing those present at the April 19th meeting of the Long Beach Section. At right are Section Chairman Frank Pope; AWS President-Elect C. P. Sander and Section Treasurer S. Walling

SAN DIEGO NIGHT HELD BY LONG BEACH SECTION

Nine members from San Diego who attended the meeting

Outstanding entertainment was provided by the Mulcaheys



IMPROVED MAGNETIC STARTER has quick response bi-metallic thermal overload relays which sense current changes and to help prevent motor burnout in case of sustained overloads or accidental single phasing. Large starter contacts are long-lasting, won't chatter.

ANNOUNCING A NEW LOOK IN M-G WELDERS!

New General Electric M-G Set Speeds Welding with Stable, Penetrating Arc—In Any Position

General Electric's new motor-generator welder gives you the stable, penetrating arc you need to get even those tough, out-of-position welding jobs done faster and better.

The secret? General Electric's NEW laminated frame welding generator, working in combination with a unique transformer reactor.

The arc is stable because this new reactor provides excellent control of current surges and assures immediate high recovery voltage at all settings. No need to worry about costly delays caused by electrode freezing or popouts.

A high level of "arc force," with the stable arc, makes the General Electric m-g set ideal for a wide variety of industrial applications, including light, medium, and heavy d-c metal-arc and inert-arc welding.

And here are just a few other reasons why the new G-E motor-generator welder answers your need for high-quality welds in less time and at less cost.

EASY TO USE—current is not sensitive to changes in line voltage—once the simple current setting has been made, no further adjustment is necessary. Arc has quick response and good control in all positions.

FUNCTIONAL DESIGN—two welding sets can be installed in the space normally required by one, saving valuable floor area—brushes can be changed while welders are stacked—cooling air enters the ends, exhausts front and back, to prevent recirculation.

LESS MAINTENANCE—constant pressure brush springs give maximum brush life—rubber-mounted, extra-width, pre-lubricated bearings require no maintenance—motor windings are Mylar* insulated and Dri-Film† coated to help prevent insulation failures—heavy-duty motor starter contacts last for years.

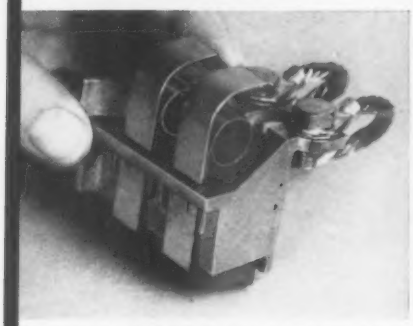
General Electric's new d-c motor-generator sets are available in both 300 and 400 ampere designs, rated 40 volts, 60% duty cycle. For more information about them, contact your nearby General Electric Welding outlet, listed in the yellow pages of your telephone book. Write for descriptive bulletin GEA-6423 to Section 711-8 General Electric Company, Schenectady 5, New York.

*Reg. Trademark of DuPont Co.

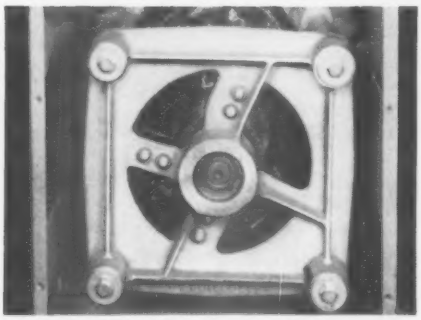
†Reg. Trademark of General Electric Co.

Progress Is Our Most Important Product

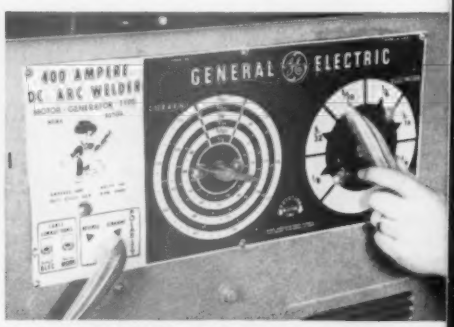
GENERAL ELECTRIC



CONSTANT-FORCE brush springs need no adjustment; give the correct constant pressure during brush life. Removable spring clips permit easy replacement of brushes.



STURDY CONSTRUCTION results from one inch diameter steel rods which link the bearing housings with welded generator and motor frames. Sturdy ¼" angles are welded to the generator frame to provide a solid base.



DUAL CONTROL DIAL is fully calibrated, easy to read. Just select electrode size on Electrode Selector, then set sensitive long-scale current control for desired welding current.

salvage of heavy equipment and steel structures. Methods and procedures used on numerous applications were described and fundamental considerations in the proper use of the process were clearly outlined.

An excellent sound and color film was shown of the 1956 Indianapolis Speedway 500 Mile Race.

LOW-ALLOY STEELS

Kansas City, Mo.—The *Kansas City* Section opened its meeting on April 11th with a Happy Hour, after which a delicious steak dinner was enjoyed at the Golden Ox Restaurant.

The speaker, John Zadra, assistant superintendent of Quality Control for the Colorado Fuel & Iron Corp. of Pueblo, Colo., gave an interesting talk on "The Production of Welding-Quality Carbon and Low-Alloy Steels." His talk consisted of the ideal chemical analysis of steels for welding and a detailed description of the phases required in the production of steel. As the talk progressed, slides were used to illustrate the details of steel production.

After completion of his talk, Mr. Zadra led a discussion period and answered many interesting questions about steel production.

WELDED PIPE LINE

Allentown, Pa.—A joint meeting of the *Lehigh Valley* Section and the ASCE was held on March 4th at Walps Restaurant, with an attendance of 84 at the dinner and 90 at the meeting.

Technical speaker Richard Van-Vliet of the Pennsylvania Power & Light Co., Allentown, discussed the new welded steel pipe line at Lake Wallenpaupack.

Slides and color movies of the old pipe line and the problems that were overcome in the design and construction of the new line were shown.

An assembly and welding yard was set up by the Bethlehem Steel Co. to fabricate the new 8-ft diam steel pipe. Assembly and welding of sections are done in this assembly yard. From the assembly yard, the sections are hauled to location by a narrow gage railroad which had been installed under the old wood pipe line. All of the old piers and pipe saddles were incorporated in the design and construction of the new pipe line.

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Company Processing Sugar Beets
They Switched to Nickel-Silver for Retreading with Wear-Resisting Build-Up Metal!
They spent $23.74 more for 100 lb. of Nickel-Silver . . . saved $150.50 in other costs incident to repair of this one spindle. They repeated on 8 spindles. All-State No. 13 Nickel-Silver Build-Up Rod is now their standard for retreading.**
ALL-STATE No. 13 is Famous for Savings!
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10 lb. No. 13 will start saving money for you. Comes bare or flux-coated.
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Ask for Buyers Guide. This is book full of product solutions to metalworking problems.
WALL CHART TO HELP YOU SELECT BEST FOR JOB FROM 86 ALL-STATE PRODUCTS
Put one up in your supply room . . . another on you shop wall . . . to help guide selection of the right Alloy and Flux for the job at hand.
19" x 22" Coated Paper
Ask your A-S Distributor for Copies. He'll also give you same data in a folder to fit 3-ring binder.
ALL-STATE WELDING ALLOYS CO., INC., WHITE PLAINS, N. Y.

BATTLE OF THE SECTIONS

Allentown, Pa.—Teams comprised of members from the Philadelphia, Susquehanna Valley, York-Central Pa. and Lehigh Valley Sections competed in a quiz program sponsored by the *Lehigh Valley* Section on April 1st.

Six rounds of questions were asked on the following subjects; Code Requirements, Welding Metallurgy, Welding Symbols, Inert-Gas Shielded Welding, Resistance Welding, and Metallurgy.

The winning panel was the Philadelphia Section consisting of Byron Gates, E. E. Goehinger and Charles Dooley who were presented with automatic pencils as prizes.

R. D. Stout of Lehigh University was the Moderator and Ralph D. Bradway, R. A. Bartholomew, George Reed and Harry F. Reid, Jr., were the judges.

PLANT VISITATION

Compton, Calif.—The first plant visitation of the year was made by 62 members and guests of the *Long Beach* Section. The plant in question is the new home of the Research Welding and Engineering Corp., located at 18201 S. Santa Fe St., Compton. This is one of the most modern welding and fabricating plants in the Los Angeles area. They do an outstanding job on aircraft and missile components.

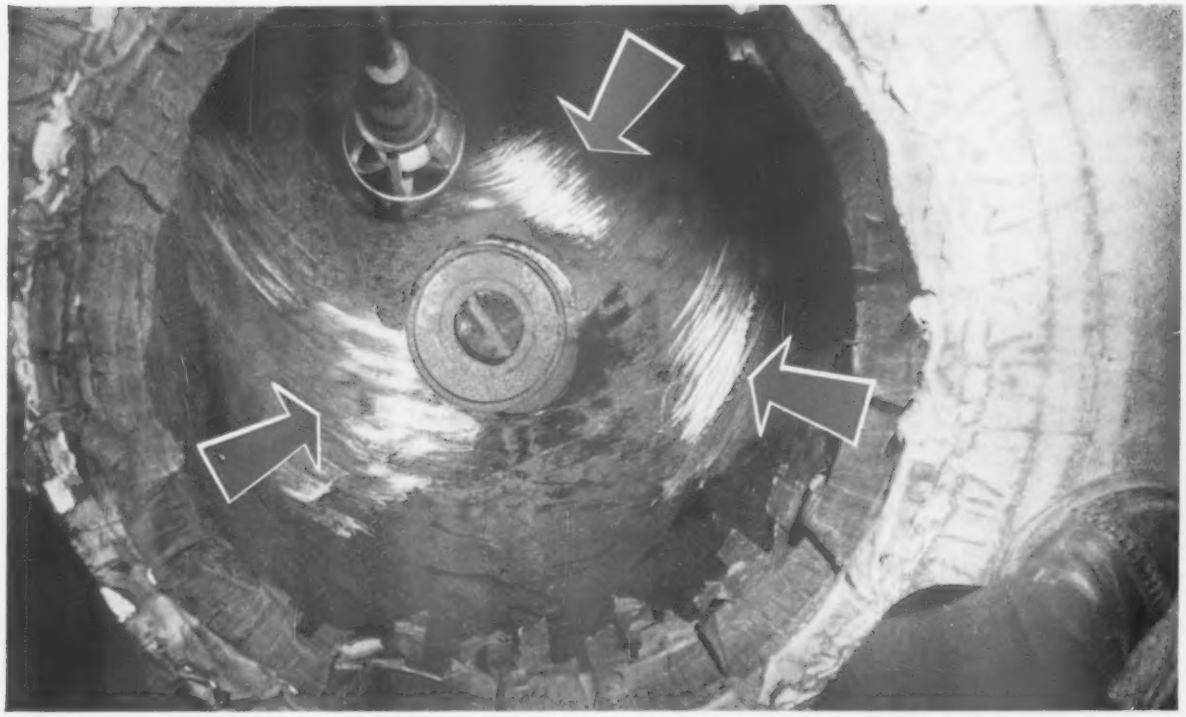
SAN DIEGO NIGHT

Long Beach, Calif.—The regular monthly meeting of the *Long Beach* Section was held on April 19th and was designated as "San Diego Night" in honor of the many members in that area. To make this an evening to be remembered the Section went all out and secured the Mulcaheys of radio and television fame for the evening's entertainment.

Featured speaker was Russell Meredith [illegible], of North American Aviation. Mr. Meredith gave an excellent presentation on "Stress Corrosion Cracking of Titanium Weldments." Mr. Meredith is an authority on gas-shielded tungsten-arc welding, and spent quite some time in answering the many questions concerning this process.

"KICK-OFF" LUNCHEON

Los Angeles, Calif.—With approximately 345 members and guests in attendance, the *Los Angeles* Section officially opened its participation in the 10th Western Metals Congress with a "Kick Off" luncheon meeting,



This large carbon-molybdenum steel valve was a total loss unless a dozen or more internal cracks could be repaired. Job was done by welding with Inco-Rod "A" electrode.

Preheat was impossible . . . yet Inco-Rod "A" saved this valve for Consolidated Edison

At first, repairing this throttle valve looked like a real headache to the Welding Department of Consolidated Edison.

The casting is made of carbon-moly steel. In service, a dozen cracks . . . some 3 inches deep . . . had developed inside its 4-inch-thick wall.

Ordinarily this would not present too great a repair problem. Use a carbon-moly electrode. To prevent air-hardening of the weld metal, *be sure to preheat to 300°F.*

But that was the catch! The valve was too big for preheating . . . and weldors would have to work inside.

Fortunately, Thomas Reilly, General Foreman, knew about Inco-Rod "A"* electrode. (Even with Inco-Rod "A" electrode, preheating is recommended when required to protect some base metals, although it is not needed for the weld metal itself.) Since the valve was a total loss, anyway, he decided it was worth a try to salvage it with Inco-Rod "A" electrode.

Working without preheat, weldors built up welds in the cracks. In a few hours the valve was saved. And today it's performing perfectly . . . operating at 925°F. and 1250 psi.

If *you* want strong, sound joints whether in repair work or in production welding of dissimilar alloys . . . consider Inco-Rod "A" electrode. A helpful folder, just off the press, gives you data on many test welds made with this electrode . . . informative case histories, too. Write today for your copy.

A few of the cracks after welding.

Inco-Rod "A" electrode gives these advantages

Versatility—This one electrode produces X-ray quality welds in *many* dissimilar alloy combinations: among ferritic and austenitic stainless steels . . . low alloy and mild steels . . . high-nickel, and other alloys.

Ease of use—With its spray-type arc, Inco-Rod "A" electrode is *easy*-handling in all positions. Slag removal is easy, too.

Corrosion resistance—Joints made with Inco-Rod "A". . . the electrode with the distinctive green flux coating . . . usually have equivalent or better corrosion-resistance than the alloys being welded.

*Registered trademark

The INTERNATIONAL NICKEL COMPANY, Inc.
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INCO-ROD "A" electrode is supplied in 14-inch lengths in four diameters, 3/32-, 1/8-, 5/32-, and 3/16-inch (the 3/32-inch is center grip) . . . packed in 5-lb. asphalt-lined containers.

INCO **Welding Products** • electrodes, wires, fluxes

held at 12 noon, March 25th in the Boulevard Room of the Ambassador Hotel.

Among the distinguished officers and guests seated at the speaker's table were President John J. Chyle, President-Elect C. P. Sander, Director-at-Large R. L. Townsend, 10th District Director C. L. Breese, Charles Ducommun, president, Los Angeles Chamber of Commerce, who gave a five-minute welcoming address, W. E. McCann, executive assistant to the Mayor, who extended the City's greetings in behalf of the Mayor, and T. B. Jefferson AWS, editor and publisher of *The Welding Engineer*, who opened the technical sessions by presenting the first paper on "Welding Codes."

AWS PANEL CONTRIBUTES TO METAL CONGRESS

"Kick-off luncheon" marking the opening of the Los Angeles Section's participation in the 10th Western Metal Congress, was held on Wednesday, March 25th

C. B. Smith, section chairman, is shown addressing those present. Placed at speakers' table are (*left to right*) AWS President-Elect C. P. Sander, Past-President J. J. Chyle, Mr. Smith, D. P. O'Connor, Chas. Ducommun, president of Los Angeles Chamber of Commerce, and J. B. Ross. Several papers were presented later at the technical sessions under the sponsorship of the Aircraft and Rocketry Panel of the Section.

Walter Tenner presenting paper on "Inert-Gas Consumable-Electrode Welding of Aluminum Alloys in Liquid Aircraft Rockets"

"Resistance Welding Controls Using Counter Tubes" was the subject of a paper by Joseph J. Riley

William R. Gain delivering his talk on "Resistance Welding of Titanium Alloy Structures"

The topic of Ernest J. Funk's paper was "The Theory and Developments of Magnetic Force Welding"

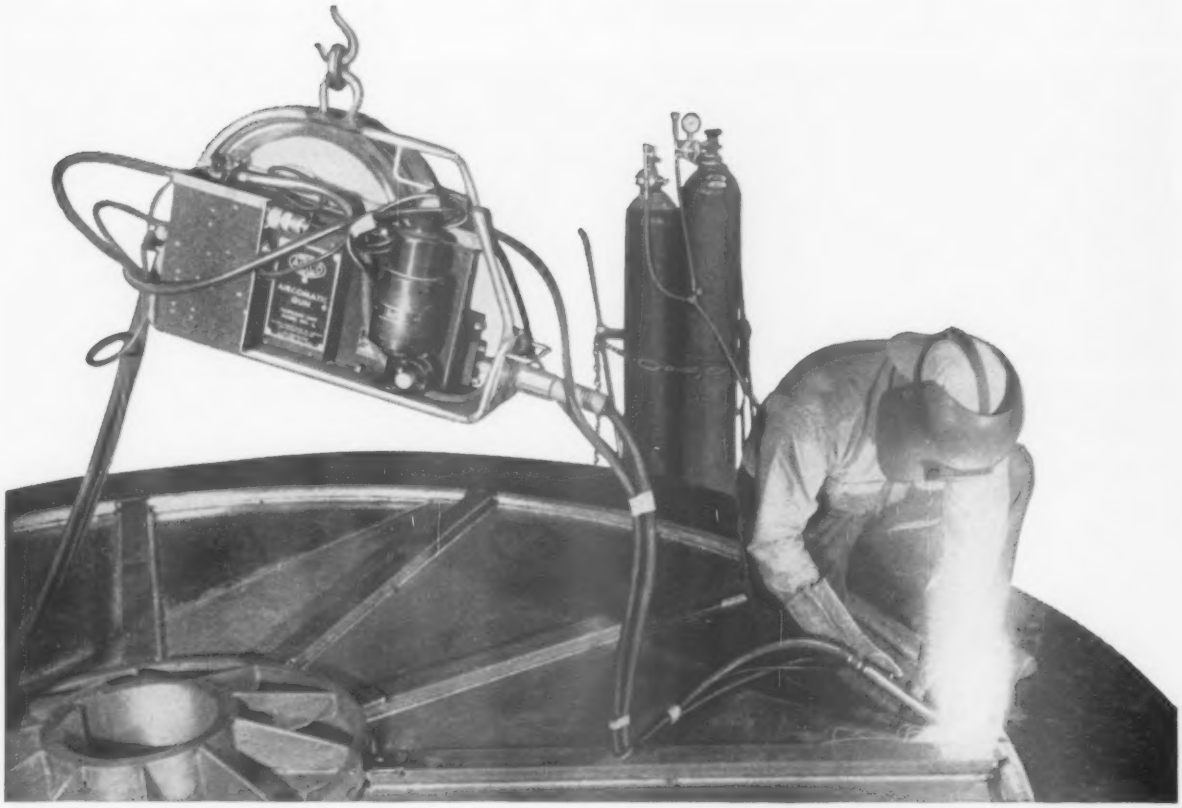
Principal speaker was National President John J. Chyle, director of welding research at A. O. Smith Corp. President Chyle's subject was "Role of Welding in Industrial Advancement." Mr. Chyle covered the art of welding from its inception to the present time, covering fully the various processes and their uses, the various types of equipment, rods and electrodes and their applicable uses in industry, costs and tonnage and the gradual increase that is constantly taking place in this method of fabrication, proving that the art of welding is here to stay. Mr. Chyle can be highly commended on his ability to hold interest in his subject, one well presented.

METAL CONGRESS

Los Angeles, Calif.—The first full day's technical sessions of the *Los Angeles* Section's participation in the 10th Western Metals Congress was held in the Sunset Room of the Ambassador Hotel on March 26th. The technical sessions for this day were six in number, obtained and presented by the Aircraft and Rocketry Panel.

Chairman for the morning session was Mario Ochieano of the Lockheed Aircraft Co. and chairman of the Aircraft and Rocketry Panel. Vice-chairman was George Foster of Air Reduction Pacific Co. Papers presented at the morning session, were in the following order: "The Theory and Development of Magnetic Force Welding" by Ernest J. Funk AWS of Precision Welder and Flexopress Corp.; "Inert-Gas Consumable-Electrode Welding of Aluminum Alloys in Liquid Aircraft Rockets" presented by Walter S. Tenner AWS, welding engineer, U. S. Naval Ordnance Test Station, which was co-authored by Paul T. Barnes, project engineer on "Lar" U. S. Naval Ordnance Test Station. The morning session was concluded by William R. Gain, general supervisor, and Dan Waite, research engineer, Boeing Airplane Co., presenting a paper titled "Resistance Welding Titanium-Alloy Structures."

Chairman for the afternoon session was Leo West of Douglas Aircraft, Inc., Long Beach Division and also chairman of the Panel. Vice-chairman was Howard Eubanks of Convair and secretary of the Aircraft and Rocketry Panel. Papers presented at the afternoon sessions were as follows: "Resistance Welding Controls Using Counter Tubes" presented by Joseph J. Riley AWS, chief electrical engineer, Taylor-Winfield Corp.; "Stress Corrosion of Titanium Weldments" presented by Russell Meredith AWS of North American Aviation, Downey, Calif. The final paper of the after-



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Aircomatic welding is an inert-gas, shielded arc process using a consumable wire electrode. The basic unit, manual or automatic, designed and manufactured by Airco, includes the welding head, carriage assembly for wire drive and control equipment, cables, hoses, and flexible wire casing.

The consumable wire electrode is produced to rigid Airco specifications as to purity, cast, and metallurgical content. Normally supplied on expendable spools, Aircomatic wire is available in aluminum, steel, stainless steel, nickel, titanium, copper, and copper base alloys.

Airco shielding gases include both helium and argon, produced by Airco, or mixtures thereof for particular requirements. Pure carbon dioxide gas is also available from Airco for use as a shielding medium where applicable.

Aircomatic is a direct-current welding process. A complete line of Airco motor-generator and rectifier type welders are designed for Aircomatic characteristics—the latest of which is a new 800 amp ACV welder.

The Aircomatic process was invented, designed, developed, and licensed by Airco. Airco's nine years of experience have given the metal working industry an inert-gas process that welds all kinds of metals – adding speed, economy and versatility to every suitable application.

An Airco Representative can give you a completely unbiased opinion as to how Aircomatic can best be employed—because—Airco is a leading manufacturer-supplier of all types of oxyacetylene, metallic arc and inert-gas shielded welding and flame cutting processes, their controls, supplies, and accessories.

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LOS ANGELES EXECUTIVE COMMITTEE MEETS WITH NATIONAL OFFICERS

Members of the Executive Committee of the Los Angeles Section are shown with AWS national officers and directors at a meeting held on Mar. 27, 1957. Section Chairman C. B. Smith is shown (*center*) at head table. Flanking him are AWS President J. J. Chyle (*left*) and AWS President-Elect C. P. Sander (*right*)

noon was presented by G. Jewett Crites, independent engineering consultant of El Segundo, Calif., titled "Vacuum Brazing of Sandwich Structures."

All sessions were well attended, and the enthusiasm shown at the question-and-answer periods was quite gratifying to all.

EXECUTIVE COMMITTEE MEETING

Los Angeles, Calif.—The executive committee of the *Los Angeles* Section met on March 27th at the Biltmore Hotel.

In addition to the chairman and committeemen, the Section was honored to have the following national officers and guests present: President John J. Chyle; President-Elect C. P. Sander; Director-at-Large R. L. Townsend; 10th District Director C. L. Breese; Past-Chairman, Santa Clara Valley, W. J. Erichsen; A. M. Hubbard, Santa Clara Valley; R. C. Wiley, Cal Poly College, San Luis Obispo; J. Magorian, San Luis Obispo; T. B. Jefferson, editor and publisher, *The Welding Engineer;* F. Pope, chairman, Long Beach Section; and Howard Eubank, secretary.

The meeting opened with a discussion of the National Educational Committee on the creation of scholarships which heretofore have been held at a college level, with a seeming lack of interest on the part of students eligible to participate. Therefore, it was suggested that such an educational program should be directed to the intermediate colleges and high schools. This was to be accomplished by the distribution of brochures explaining the need of welding technicians and engineers, along with the possibilities one may have in this field.

Mr. Chyle emphasized the importance of the educational program to the U. S. industry, stating that Russia is progressing rapidly in this direction with 12 schools graduating 500 welding engineers this year with a Ph.D. or Masters degree. He also presented the possibility of contacting large industrial organizations for financial support.

The chairman called upon Mr. Chyle who reported on and discussed a number of national problems with the committee members. Among the topics discussed was the need for a more suitable national headquarters.

ROLL PLANISHING

Huntington Park, Calif.—Fifty-seven members and guests of the *Los Angeles* Section gathered at the Elks Club in Huntington Park on April 18th to enjoy cocktails, dinner and to hear Harlan Meredith AWS, vice-president of the Airline Welding and Engineering Co., Hawthorne, Calif., present an excellent paper on roll planishing. Roll planishing was graphically presented with the use of slides, and narrated by the speaker in a manner that conveyed full knowledge of his subject to the audience. Mr. Meredith explained how the loss in weld joint strength was attributable to four factors, the foremost being a loss in tensile strength due to the weld being a cast structure, the second factor being a loss of ductility, the third being the notch effect caused by abrupt change in thickness at the weld edge and the fourth factor being attributable to the enlarged grain structure of the heat-affected zone; i.e., the transition from cast structure to lamellar not being uniform. He explained how the major problem in welding or the end point was to obtain 100% joint efficiencies, the proper application of the welding torch or electrode only permitting 80 to 90% in joint efficiencies.

Mr. Meredith explained how this obstacle confronting the welding industry could be overcome by the use of roll planishing after welding, and how this increased joint strengths and appearance in certain types of welded

AT APRIL 18TH MEETING OF LOS ANGELES SECTION

President-Elect C. P. Sander talks on national affairs before the assembled members and guests of the Los Angeles Section at the April 18th meeting. D. P. O'Connor, acting section chairman, and Harlan Meredith, guest speaker, listen attentively

Mr. Meredith delivering his paper entitled "Roll Planishing Improves Weld Joint Efficiency and Quality."

products. Charts describing the various manners in which the equipment could be used, to contribute to greater joint efficiencies and the difference in strengths obtained in various materials by its use, were shown and well explained.

INERT-ARC WELDING

Louisville, Ky.—Harry D. Mann AWS, Air Reduction Sales Co., was the guest speaker at the April 23rd dinner meeting of the *Louisville* Section, held at the White Cottage Restaurant, Louisville, Ky.

Mr. Mann gave a very interesting talk on the development of the inert-arc cutting process with the aid of slides and high-speed movies of the arc cutting.

A lively discussion period followed the lecture, and it was felt that a very worth-while evening had been enjoyed by all.

PANEL DISCUSSION

Madison, Wis.—The *Madison* Section held a panel discussion on April 11th at the Eagles Club House. This was the second such forum held by the section this year. The members of the panel were selected to include as many various phases of welding as possible—stainless steel fabrication, mild steel, fabricating industry, design and procedure, and education. Panel members were Charles Druetzler of Fairbanks Morse Co., Arnold Ehle of the Wisconsin Foundry & Machine Co., Alex Falch of Krueger Fabricating Co. and James Brunt of the Beloit Vocational School. Moderator was Fred Theiler, welding instructor for Madison Vocational School.

The questions raised from the floor were actual cases of difficulties experienced on the job.

The majority present felt the meeting was a great success.

INERT-ARC CUTTING

South Bend, Ind.—The *Michiana* Section turned to gas-shielded tungsten-arc cutting for its subject on March 21st. H. M. Gregoire, sales representative for the Chicago office of Linde Air Products Co., presented a very lucid and interesting description of the process. This relatively new means of cutting metallic materials is particularly adapted to aluminum. Consisting of a modified gas-shielded tungsten-arc electrical circuit and using a helium-hydrogen atmosphere, the process is amenable to both hand and machine cutting. A higher proportion of hydrogen is used in the machine operations and high cutting speeds can be obtained. Not only cutting, but gouging can be accomplished by this process.

AUTOMATIC WELDING

Newark, N. J.—A capacity audience of 105 members and guests of the *New Jersey* Section were present on April 16th at the Essex House Hotel in Newark to hear John A. Headaphol AWS speak on "Automatic Welding with Constant Voltage." Mr. Headaphol, a graduate of Ohio State University with a B.S. in Mechanical Engineering and at present with Hobart Brothers Co. in their Automatic Welding Division, spoke of the inherent advantages of constant voltage in automatic welding, i.e. simplicity of a single control for amperage and absence of burn back or shorting out of the electrode. The versatility of constant voltage welding was illustrated by slides showing installations using submerged arc, inert arc and CO_2 welding on steel, aluminum and stainless steel.

A dinner preceded the technical meeting, followed by a film entitled "Eye To The Unknown" portraying the new tool of science, the "Mass Spectrometer."

There was the usual after-meeting social get-together and refreshments.

●

The New Jersey Section sponsored $50 in prizes for a Membership Contest which ran from October 1956 to April 16, 1957.

The Contest netted 35 new members.

The winners were: 1st place, $20—Ralph Minga (Linde Co.)—8 new members; 2nd place, $10—George Kotcher (Air Reduction Co.)—6 new members; 3rd place, $8.00—Leonard Baum (Wright Aeronautical Division)—5 new members; 4th place, $7.00—John Hila (Foster Wheeler Co.)—4 new members; 5th place, $5.00—Milton Halliburton (United Engineers)—3 new members. Honorable mention was given to Frank Hoffman (Todd Shipyards), C. L. Sullivan (Air Reduction Sales), Steve Sullivan (Air Reduction Sales), Frank Vigani (Esso Standard Oil) for obtaining two new members each. In addition to cash awards, Certificates of Appreciation were also given by Membership Chairman Tom McElrath (Linde Co.)

METROPOLITAN WELDING CONFERENCE

New York, N. Y.—The first Metro-

HEADAPHOL SPEAKS BEFORE NEW JERSEY SECTION

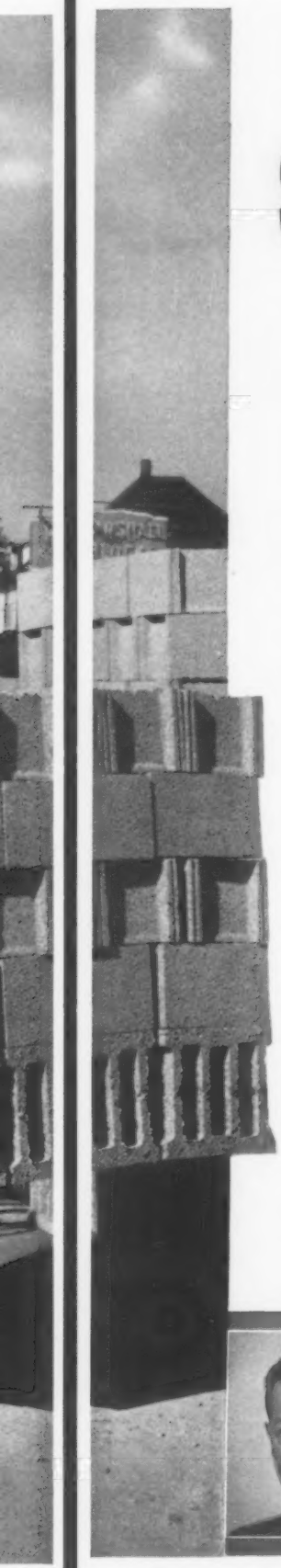
Partial view of large crowd assembled at the April 16th meeting of New Jersey Section

Guest speaker John A. Headaphol delivering his talk on the inherent advantages of constant voltage in automatic welding

Membership Contest winners were *(front row, left to right)* John Hila, R. Minga, T. McElrath; *(back row, same order)* M. Halliburton, G. Kotcher and L. Baum.

NEWSFRONTS

Units made by Erickson Power Lift Trucks, Inc., have capacities of from 2000 to 20,000 lbs. Prime requisite of welds must be strength and rigidity to withstand sudden and varying loads.



Putting bonus muscle in a

small but mighty weight lifter

Erickson Power Lift Trucks, Inc., standardizes on versatile, easy-to-use A. O. Smith SW-15 (E-6013) electrodes

MINNEAPOLIS, MINN. — When a company uses one type of electrode exclusively, it's a good indication that their experience has proved those electrodes do a better job at lower overall cost. As George Erickson, Jr., puts it, **"We've standardized on A. O. Smith SW-15 (E-6013) electrodes because we believe that for quality and uniformity, they're the very best available".**

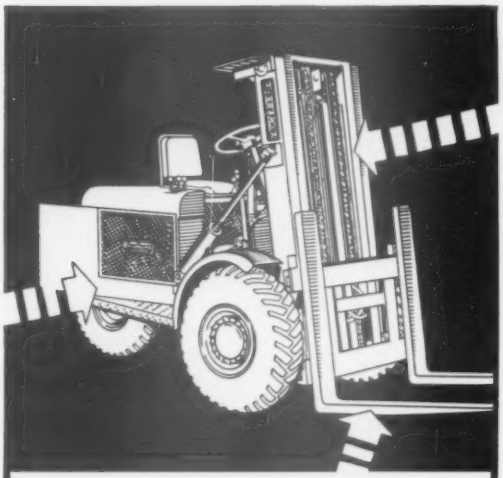
Used on Both Light and Heavy Plate

And no wonder. The SW-15 is a high-production mild steel electrode that can be used with equally good results on light or heavy plate. Weld metal has excellent mechanical properties and good X-ray quality . . . high heat and speeds can be used without risk of undercut . . . and on single pass or finish welds, slag is self-peeling.

If you'd like to know how you, too, can benefit by standardizing on A. O. Smith electrodes, contact your "man from A. O. Smith". He'll be pleased to give you the complete story.

The man from A. O. Smith . . .

John Rehm is the A. O. Smith welding consultant who worked with Erickson. More than a salesman, he's a welding specialist, ready and eager to help with any welding problems.



Critical areas requiring extremely high physical standards are indicated. SW-15 meets all requirements.
Typical mechanical properties:

	As Welded	Stress Relieved
Yield Point psi	67,900	65,000
Tensile Strength psi	76,400	72,700
% Elongation in 2"	21.5	24.5
	X-Ray Quality	

Through research A.O. Smith *. . . a better way*

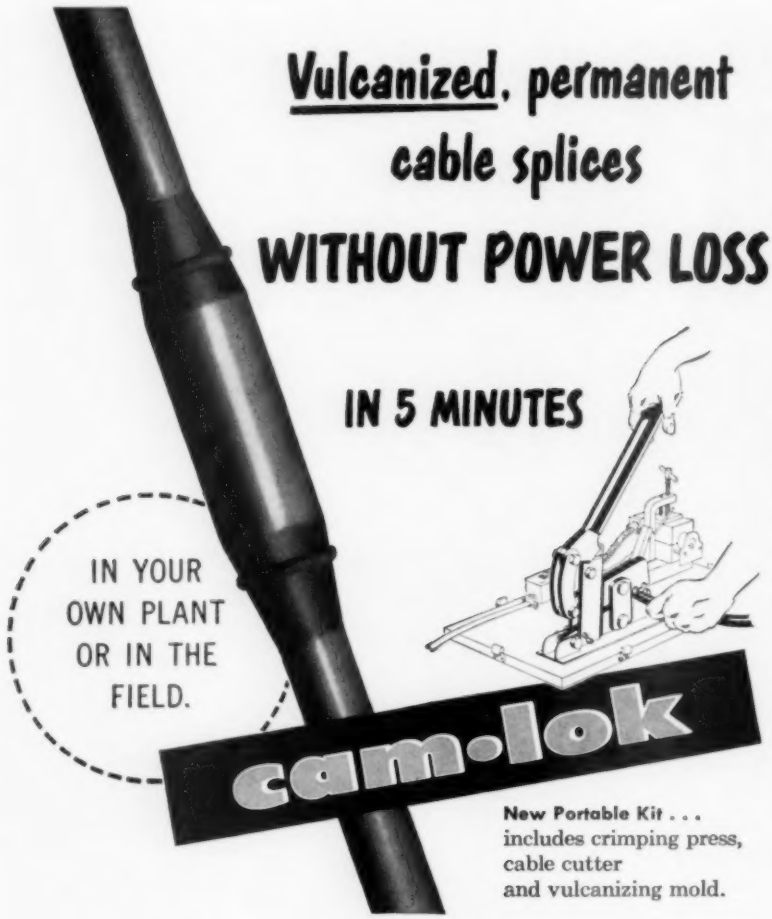
A.O.Smith

CORPORATION

WELDING PRODUCTS DIVISION

MILWAUKEE 1, WISCONSIN

International Division: Milwaukee 1, Wisconsin



New CAM-LOK portable Cable Splicing Kit produces vulcanized, neoprene insulated cable splices anywhere in just 5 minutes . . . makes them waterproof, shockproof.

Simply strip back insulation on cables . . . insert bare ends in copper tube supplied . . . crimp . . . place inner sleeve over crimp . . . vulcanize outer sleeve to cable jackets. No tools or experience needed . . . no production delays.

- Insulating sleeves are vulcanized to cable . . . can't pull away . . . prevents moisture from entering and damaging cable.
- Conductivity of splice is as good as the cable itself. Cables are crimped under great pressure into a pure copper crimping tube.
- Completed splice is tapered and only slightly larger than cable, so cable won't be caught on obstructions when dragged.
- Economical . . . because of low cost of components . . . allows you to splice as little as two, 2′ sections together, which might otherwise be wasted.
- Splice is flexible, because inner sleeve eliminates voids or weak spots in the insulation.
- Finished insulation of splice will withstand 2,500 volts without any leakage.

Bulletin No. 243 contains full information on this new Kit and Cable Splice. Write today for your copy.

CAM-LOK Division
Empire Products, Inc.
P. O. Box J-98, Cincinnati 36, Ohio

politan Welding Conference sponsored by the *New York* Section in conjunction with the *New Jersey* and *Long Island* Sections was held on March 27, 1957, at the Midston House.

Over 100 members and guests attended this all-day session which included several papers on diversified welding and brazing subjects.

The speakers and their subjects were J. Cavanaugh AWS, Alloy Rods Co., "Low-Hydrogen and Iron-Powder Electrodes"; J. E. Dato AWS, Linde Co., "Role of Inert-Gas Welding in Industry"; A. N. Kugler AWS, Air Reduction Sales Co., "Safety"; A. W. Swift AWS, Handy & Harman, "Silver Brazing"; J. Imperati AWS, American Brass Co., "Bronze"; J. A. Goodford AWS, Crucible Steel Co., "Welding of Stainless Piping"; and Ken Spicer AWS, International Nickel Co., "Welding Nickel and Dissimilar Alloys." All talks were illustrated with appropriate slides.

There was one central theme which was reiterated by all the speakers. It was—"Welding Is Growing. Let's All Grow with It."

PANEL DISCUSSION

New York, N. Y.—The last meeting of the current season of the *New York* Section was held on April 16, 1957. The meeting consisted of a symposium with four speakers and one moderator.

The symposium or panel discussion had as a main topic "How To Run a Modern Welding Shop—Profitably," a subject which created considerable interest. The first speaker, Dudley Lowland of H. F. Butler and Co., Union, N. J., covered "Estimating," and told the audience the care that must be given to the various items that go into a good estimate. The speaker emphasized that many times the designers do not include all details and must be returned to them for clarification. The welding shop must study the process that is to be used as compared to the equipment that is available. In addition to this, welding variables such as tolerances and warpage must be considered. The required strength of the welds must also be considered and last, but not least, the procedure that must be used.

"What to Do with Idle Time" was covered by John Cianflone AWS, president of the CBC Welding Corp., New York City. This topic is, and will remain, a problem to any welding shop as the owner finds himself in a position that there is either too much to do or not enough to do. Laying off welders during slack or idle periods will result in undue loss of personnel,

and to keep them during idle periods may bring the cost of the shop up to a point where the owner cannot carry the load. Advanced planning, together with overhaul of equipment, will tend to keep the shop going.

"Welding Equipment, Electrodes and Supplies" was next discussed by Merle Dillman AWS, welding engineer of the Worthington Corp. Mr. Dillman mentioned that automation is coming more and more to the forefront and must be considered in every welding shop. Care of electrodes and what electrodes to stock was outlined by the speaker, as well as selection and maintenance of equipment, all important factors.

"Welding Procedures and Quality Controls" was the topic of the talk given by Vito DiGiglio AWS, welding engineer for the Naval Ship Yard, Brooklyn, N. Y. Mr. DiGiglio also emphasized the importance of the selection of processes and procedures, and explained in detail both what a process is and what a procedure is in accordance with today's standards. Operator qualifications and procedure qualifications, according to the welding codes, were also discussed. Finally, inspection for physical defects, as well as tests that had to be made under contract, were explained to the audience.

H. D. Landis, Jr. AWS, Armco International Corp., was the moderator. Mr. Landis did a good job in keeping the meeting on a very interesting basis and bringing forth many questions from the attentive audience. J. E. Mooney of the New York Trade School also contributed to the success of the meeting.

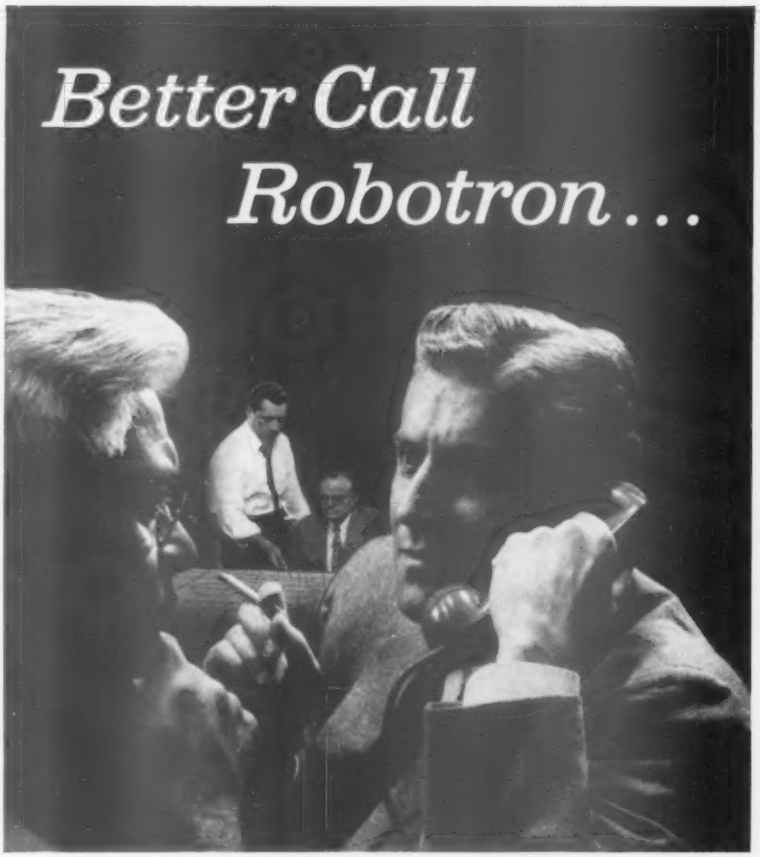
This was the last meeting of the season and was well attended. The technical chairman was Dan Bellware. As usual, the meeting was held at Victor's Restaurant, 1 E. 35th St., New York City, and a good dinner was served prior to the lectures.

ANNUAL LADIES NIGHT

Marion, Ohio.—Forty-nine couples attended the third annual Ladies' Night of the *North Central Ohio* Section held on April 5th. The dinner-dance was held at the Marion Country Club. Upon arrival each of the ladies was presented with a corsage.

The cocktail hour before dinner was enjoyed very much and offered an opportunity for the wives of the members to renew acquaintances made at the previous Ladies' Night dinner.

A delicious dinner was served by the Marion Country Club. After dinner, door prizes were awarded to the lucky couples. Dancing was en-



Faced with the problem of brittleness in high carbon steel welds, this manufacturer called in Robotron for special assistance. Robotron engineers quickly determined the trouble, and recommended the application of an up-down slope control unit to the welder. *Result:* the down slope portion of the unit controlled after-weld heat so that the weld was annealed and brittleness was reduced to a minimum.

Today, practical solutions to *many* welding control problems are found through the correct application of Robotron products—designed by electronic specialists to control the heat, timing and placement of the weld nugget for more efficient precision welding . . . even on hard-to-weld metals.

Let Robotron's experienced staff *team up* with you to solve your control problems. They can help you improve product quality and reduce costs. Call them today.

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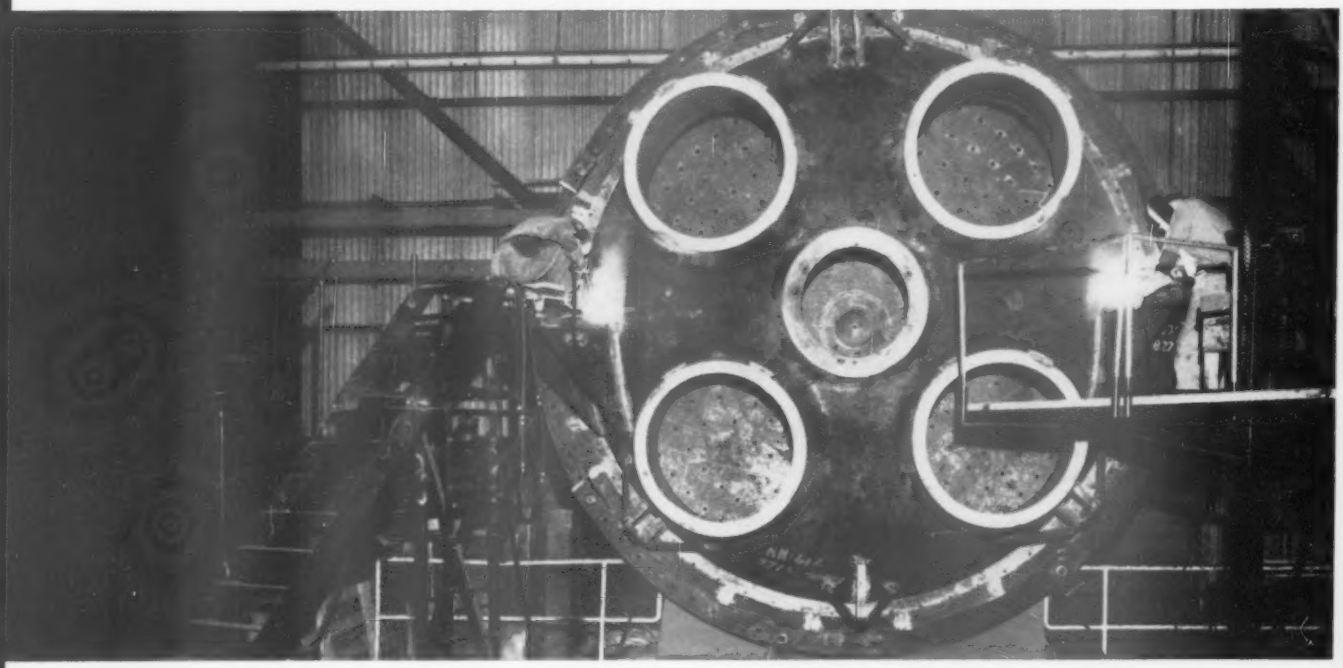
In October '54, the welding habits of America were changed by the introduction of Atom • Arc, the first all position iron powder low hydrogen electrodes.
Now, equally important changes are taking place with the NEW . . .

ATOM·ARC DH-12

IRON POWDER LOW HYDROGEN ELECTRODES FOR DOWN HAND WELDING



NEW ATOM•ARC DH Electrodes deposit up to 12 pounds of weld metal per hour with X-ray quality and physical properties equal to class E-7016 electrodes.

Just imagine, the visibility and flexibility of metallic arc welding with welding speeds and deposition rates comparable to semi-automatic submerged arc welding . . . and without messy fluxes or cumbersome equipment to handle. These advantages are yours with these *new* electrodes.

ATOM · ARC DH-9 FOR DOWN HAND WELDING AND HORIZONTAL FILLETS deposits X-ray quality weld metal at the rate of 9 pounds per hour at 300 amps. Burn off rate is 12.4 inches per minute.

ATOM · ARC DH-12 FOR DOWN HAND WELDING deposits X-ray quality weld metal at the rate of 12 pounds per hour at 360 amps. Burn off rate is 11.9 inches per minute.

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DH-

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NO FINER ELECTRODES MADE . . . ANYWHERE

joyed from 9:30 to 12:30 to the accompaniment of Jim Minium's orchestra. The evening was very successful.

NUCLEAR REACTOR VESSEL

Oak Ridge, Tenn.—At a dinner meeting held on April 15th, E. C. Miller of the Oak Ridge National Laboratory and director of District No. 4, addressed the *Northeast Tennessee* Section on the unusual design and fabrication problems that are encountered when planning a nuclear reactor vessel. Mr. Miller's discussion concerned the applicability of the Boiler Code, including the fabrication techniques and inspection methods used. The particular vessel was a 36-in. diam by $^1/_2$-in. thick Zircaloy-2 spherical vessel backed by a 4.4-in. carbon steel, stainless-clad pressure sphere. The outside vessel was 1-in. thick carbon steel.

This reactor was designed to obtain data on life expectancy for use in design of power reactors. Operating conditions were 2000 psi at 1500° F, which are considered typical for this type of reactor. Observations were to be taken on the radiation and neutron bombardment effect on the strength of the materials, creep data and stress rupture values at certain critical points.

The weldments were made by Lukens Steel Co. and the Newport News Shipbuilding and Dry Dock Co. All of the welding was performed on welding positioners rotating the work under a stationary welding head. Extra precautions were taken to insure inert-gas coverage during and immediately following the welding operation. The final weld on the 4.4-in. thick shell joined the two hemispheres together to complete the sphere. Since the openings were not large enough to permit welding from both sides, the complete penetration weld had to be obtained from the outside. Four different alloy rods were used from the first sealed weld to the final pass. Procedures for gamma-graphing, X-raying and liquid penetrant inspections of weld passes were developed to insure that the quality requirements of the joint were met.

The successful completion of the fabrication and testing of this nuclear reactor vessel illustrates the desire and capability of private companies to undertake work of this nature.

The new silicon rectifier means money in your pocket

. . . money you'll save because this revolutionary Westinghouse welding development has been proved by industry to be the most efficient, most durable ever offered. It's hermetically-sealed against dust, oil, water and acid fumes. And for the welding operator there's excellent performance — easier arc starting, better arc stability, maximum drive.

The new silicon rectifier is another milestone in welding, another Westinghouse *plus* that teams with "wide-amp" control and "arc-drive" control to bring you the *best* in welding equipment. J-21983

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WELDING DISTORTION

Erie, Pa.—LaMotte Grover AWS, welding engineer, Air Reduction Co., New York was the guest speaker at the April 16th dinner meeting of the *Northwestern Pennsylvania* Section held at Larson's Restaurant.

Mr. Grover discussed the practical methods of distortion control in steel construction and plate-assembly work, covering welding procedures and sequences, mechanical restraint and support and details of design, as well as correction by oxyacetylene flame shrinking.

RESISTANCE WELDING APPLICATIONS

Bradford, Pa.—Technical production factors were discussed at the April 23rd meeting of the *Olean and Bradford* Section held at the Hotel Emory at Bradford.

J. H. Cooper AWS, chief sales engineer of Taylor-Winfield Corp., Warren, Ohio, spoke on special resistance welding applications. Two half-hour films were shown in conjunction with the talk.

Forty members and guests attended this monthly dinner meeting under the chairmanship of Harold Collins of the Dresser Manufacturing Division.

MOTION PICTURES

Portland, Ore.—The March meeting of the *Portland* Section was held

WELDING SUPPLIES
PLATING MATERIALS • ORGANIC COATINGS
CERAMIC MATERIALS • TIN & TIN CHEMICALS
METALS & ALLOYS • HEAVY MELTING SCRAP

Welding Progress

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EASIER SELECTION OF HARD SURFACING ELECTRODES

Companies in the heavy equipment field are reporting that hard surfacing operations have been simplified and improved with a new line of Hardex electrodes introduced by Metal & Thermit late last year. Matching of hard surfacing deposits to service requirements has been simplified; better physical properties of the overlays lead to increased resistance to wear and reduced maintenance costs. A manual, giving details on hard surfacing systems using the new Hardex Electrodes, is available without cost from Metal & Thermit.

Improvements noted in using these electrodes include decreased porosity in the weld metal, increased resistance to cracking, decreased penetration accompanied by excellent fusion, and decreased weld metal dilution. The reduction of penetration and minimized dilution of weld metal is reported to reduce the amount of surfacing material required to obtain the desired deposit analysis.

A wide variety of hard surfacing requirements is covered by the 16 electrodes in the Hardex line. A manual with a selector chart listing the right Hardex electrode for over 200 hard surfacing applications may be obtained by writing Metal & Thermit. Complete with helpful information on each electrode, it is an invaluable guide to both the weldor and purchaser of hard surfacing electrodes.

Change in Electrodes Solves Stainless Welding Riddle

The proper selection and application of stainless steel electrodes demands a knowledge of the steel being welded as well as the composition of the electrode itself.

A case in point is a Midwestern manufacturer who was joining selenium-bearing stainless fitting to columbium-modified 18-8 stainless, with titanium coated electrodes. Gas was forming in the welds and producing pinholes . . . a phenomena finally attributed to the high titanium content of the electrode coating reacting with the selenium steel. An M&T representative solved the problem by substituting Murex lime-coated stainless electrodes which contained less than 8% titanium oxide.

Metal & Thermit's line of stainless electrodes includes chrome-nickel grades for austenitic and extra low-carbon steels, straight chromium grades for ferritic and martensitic steels. For a complete list of these electrodes and how to apply them write for booklet S-56.

New Welder Rated at 100% Duty Cycle

Long, trouble-free service at a full 100% rated duty cycle is now possible with the M&T Controlled Arc Power Supply recently introduced by Metal & Thermit for automatic welding. With an efficiency of 85%+ and a power factor of 90%+, the C.A.P.S. unit offers lower installation and operating power costs.

Delivering DC welding current at constant, preset voltages, the machine has a built-in arc characteristic control that cushions the effect of current surges, an especially desirable feature in low current density welding of light gauge metals. By reducing wide current fluctuations, the CAPS machine permits deposition of more metal per pass, and improves the overall quality and appearance of the weld. When teamed with a CAPS Constant Speed Wire Feed and gun, the combination provides a complete welding package that reduces the cost of all types of semi- and full-automatic welding. For full details, write to Metal & Thermit Corporation, Rahway, N. J.

at Heathman Hotel on March 12th.

Three motion pictures, which were very well received, were shown as follows: (1) "U. S. Steel Presents T1," courtesy of U. S. Steel Corp.; (2) "Fiery Magic," courtesy of Air Reduction Co.; and (3) "The Petrified River," a story of origination and mining of uranium, courtesy of the Union Carbide & Chemical Co.

RESISTANCE-WELDING APPLICATIONS

Rochester, N. Y.—The *Rochester* Section's regular business meeting convened at the Liederkranz Club on Monday, April 15th. Chairman Robert Barr opened the meeting by announcing that Walter Dick had received the AWS Meritorious Service Award. Mr. Dick has been a member of the Rochester Section for the past 18 years and has served in numerous capacities. He was also instrumental in the development of the underwater welding of stainless steel fabrications. A loud ovation greeted this announcement and all warmly congratulated Mr. Dick.

The technical speaker for the evening was William J. Farrell AWS, chief application engineer of Sciaky Bros., Inc.

The title of Mr. Farrell's talk was "Principles and Applications of Resistance Welding" and, using slides as well as blackboard demonstrations, he did an excellent job of presenting his topic. Mr. Farrell pointed out that resistance welding is responsible in a large measure for our improved standards of living, being especially instrumental in the production of transportation equipment. The four types of resistance welds covered were spot, projection, seam and flash-butt welds. He also described how the heat for welding in a resistance welding process is generated by the electrical resistivity of metals to the passage of electrical current. In discussing each of the four processes, he described the fundamentals of technique and then described several applications in some detail.

In concluding, Mr. Farrell summed up the advantages of resistance welding as follows: (1) Offers weight saving; (2) often offers superior strength over other methods of fabrication; (3) improved appearance; (4) aerodynamically smooth; little or no warpage; (6) corrosion resistance is excellent due to lack of a third material and/or a flux; (7) can provide a leak-tight weld; (8) can be made automatically and is always reliable; and (9) is the least expensive of the welding processes.

A rising vote of appreciation was given to Mr. Farrell at the close of the meeting.

LEE SPEAKS ON IRON-POWDER ELECTRODES

Richard K. Lee addressing the San Francisco Section on "Low-Hydrogen Iron-Powder Electrodes" at the April 1, 1957, meeting in Berkeley, Calif.

Program Chairman S. I. Roberts, President J. J. Chyle, Mr. Lee and Section Chairman Fred Stettner, exchanging pleasantries

PROCESSES AND PRODUCTION

Saginaw, Mich.—Because of heavy fog and rain, the scheduled speaker, Gordon Parks AWS, of Solar Aircraft, Des Moines, Iowa, was unable to fly to Saginaw in sufficient time to speak at the technical session of the *Saginaw Valley* Section meeting on April 4th. However, Vice-Chairman Fred Williams came to the rescue and presented an extremely interesting and diversified program that received many favorable comments by both members and guests.

First, the Past-Chairman's program was presented by Bill Moehring (1955–56) citing the growth of the Saginaw Valley Section from its first start back in 1947 to its present solid position of 151 members and an average meeting attendance of over 65 persons.

For a substitute program the audience heard four very fine talks, although the speakers had less than four hours in which to prepare their material:

Paul Klain AWS, Dow Chemical Co., talked about magnesium, its weldability and many uses.

Dean Knight AWS, National Electric Welding Machines, presented slides and a fine talk on mash-seam welding.

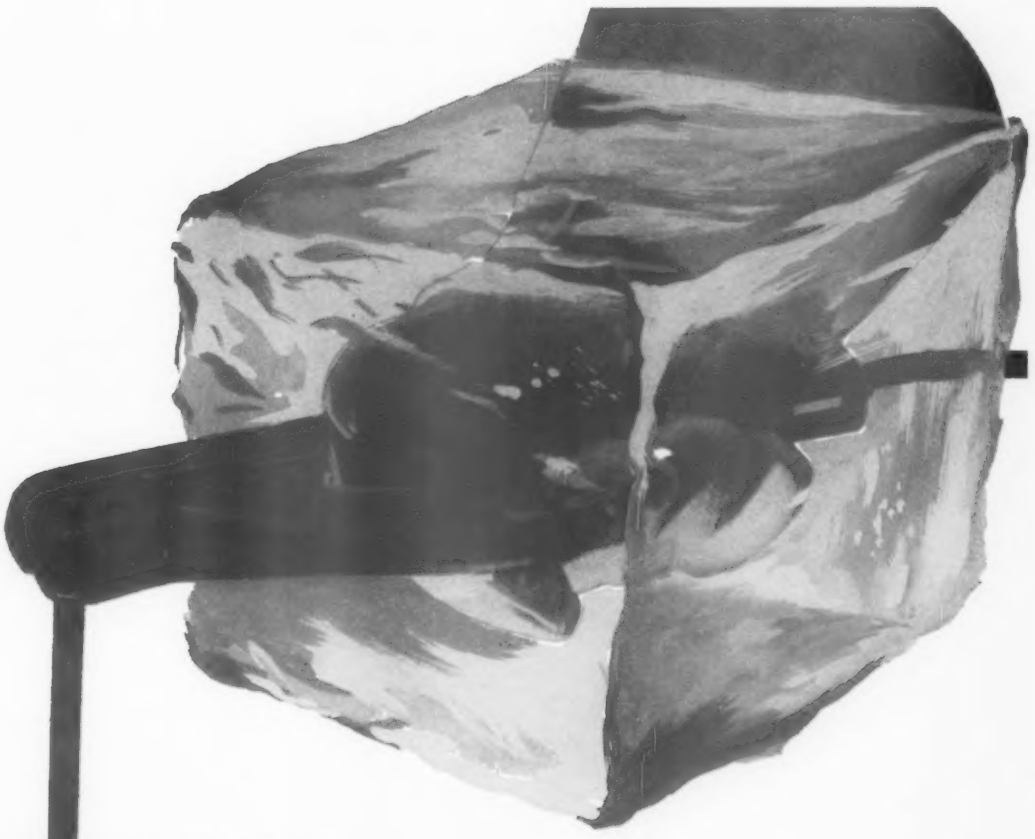
Fred Williams of Buick Division talked about arc welding and the associated problems he has encountered.

Larry Elliott AWS, Bay Products, presented a graphic picture of the recent application of Dekatron tubes to resistance welding timer circuits.

All of the talks were extremely interesting and the Saginaw Valley Section is proud to have individuals such as these men included in their membership.

LOW-HYDROGEN ELECTRODES

Berkeley, Calif.—Richard K. Lee, vice-president, Alloy Rods, York, Pa., addressed the *San Francisco* Section at Spenger's Fish Grotto in Berkeley on April 1st. In his paper on "Low-Hydrogen Iron-Powder Electrodes," which followed a coffee talk by National President John J. Chyle on the activities of the So-



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Lincoln Cooltong—Hand stays cool. It's light, well balanced, easy to use in any position. Rugged too! Drop it, step on it, drag it... it won't short.

300 amp. Light Weight

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The World's Largest Manufacturer of Arc Welding Equipment

When welded aluminum must meet exacting standards...severe service

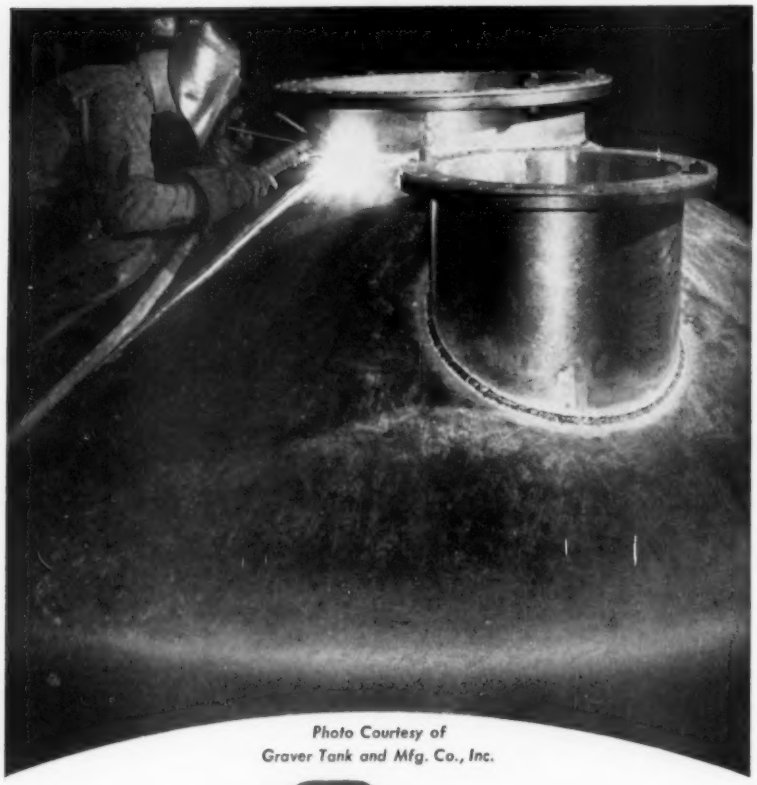


Photo Courtesy of Graver Tank and Mfg. Co., Inc.

WELD WITH ARCOS

ALUMINUM RODS and ELECTRODES

The inert-gas-shielded-arc process made aluminum welding practical . . . but it takes Arcos quality in aluminum bare wire to assure you the most dependable results possible. Because no flux is used, the chemical analysis and cleanliness of the wire must be within exacting limits. Arcos' long experience with weld metallurgy, plus rigid controls in manufacturing, guarantee this vital factor. Arcos aluminum wire is your best assurance of stronger, more ductile, more corrosion-resistant welds.

ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

CIETY, Mr. Lee described the advantages and shortcomings of conventional low-hydrogen electrodes and asserted that the addition of iron powder to the coating had resulted in rates of deposition equal to or greater than conventional electrodes, that the iron powder in the coating had given stability to the arc, had permitted automatic control of its length, had made it possible to eliminate porosity, had allowed higher deposition rates at higher current without greater base metal penetration, had provided positive means for preventing splatter and had given better deposition control in out-of-position welding.

He illustrated his talk with slides and demonstrated, by pictures of welds, the advantages which he claimed for low-hydrogen iron-powder electrodes.

Many of the 70 members attending the meeting participated in the objective question-and-answer period that followed this interesting paper.

T-1 STEEL

San Jose, Calif.—On February 26th the *Santa Clara Valley* Section held a Student's Night with representation by students of the California State Polytechnic College. The dinner and meeting took place at the Mary Ann Garden in San Jose. Coffee speakers from the Cal Poly College gave short talks on "AWS at Cal Poly" and a short talk was also given by Ralph Miller, secretary of Cal Poly, on "Welding Design Lab at Cal Poly."

The principal speaker of the evening was Leon C. Bibber AWS, chief research engineer of welding for United States Steel Corp., Applied Research Laboratory, Monroeville, Pa. His talk was illustrated by slides and a movie showing the testing of 8 full-scale pressure vessels made of USS "T-1" steel. Data pertaining to the fabrication and general engineering applications of "T-1" steel was thoroughly covered and illustrated.

CARBON-DIOXIDE WELDING

San Jose, Calif.—The *Santa Clara Valley* Section was very fortunate to have as its speaker, at the April 2nd meeting, National President John J. Chyle of the A. O. Smith Corp. Mr. Chyle's talk on carbon-dioxide welding included the basic fundamental reactions of carbon-dioxide gas in an arc atmosphere and the advantages of this process were discussed. Comparisons were made with other welding processes and typical

applications of this process were illustrated. The talk also included the requirements for obtaining the optimum in welding properties, and described in detail the welding procedures used. The outstanding characteristics of this process were explained and the metallurgical and physical properties of the weld metal were discussed.

CLAD STEEL

Shreveport, La.—The March meeting of the *Shreveport* Section was held on March 21st at the Captain Shreve Hotel.

Educational speaker was Louis K. Keay AWS of the Lukens Steel Co., Coatesville, Pa. Mr. Keay's subject was "Manufacturing, Fabricating and Application of Clad Steel."

Mr. Keay defined clad steel as composite material, sheet or plate that consists of a less expensive metal, such as carbon steel, on one side and a thinner sheet of high-alloy metal such as nickel, stainless steel, copper, etc., on the other side. The two plates may be brazed together to make clad material. Another method is to weld two heavy slabs together around edge heat to 2300° F and pressure weld the two together by rolling. With either method of producing clad material, the bond is very good; however, the two surfaces must be clean when put together. AWS requires that the bond have a tensile shear strength of 20,000 psi. The bond area of most clad materials has a strength of 40,000 psi or more.

Mr. Keay gave the following steps in fabricating steel: (1) bevel steel plate leaving a $^1/_{16}$-in. lip of carbon steel; (2) weld carbon steel from carbon steel side and (3) gouge out back of carbon steel weld and weld alloy side with electrode of higher alloy analysis than the clad alloy.

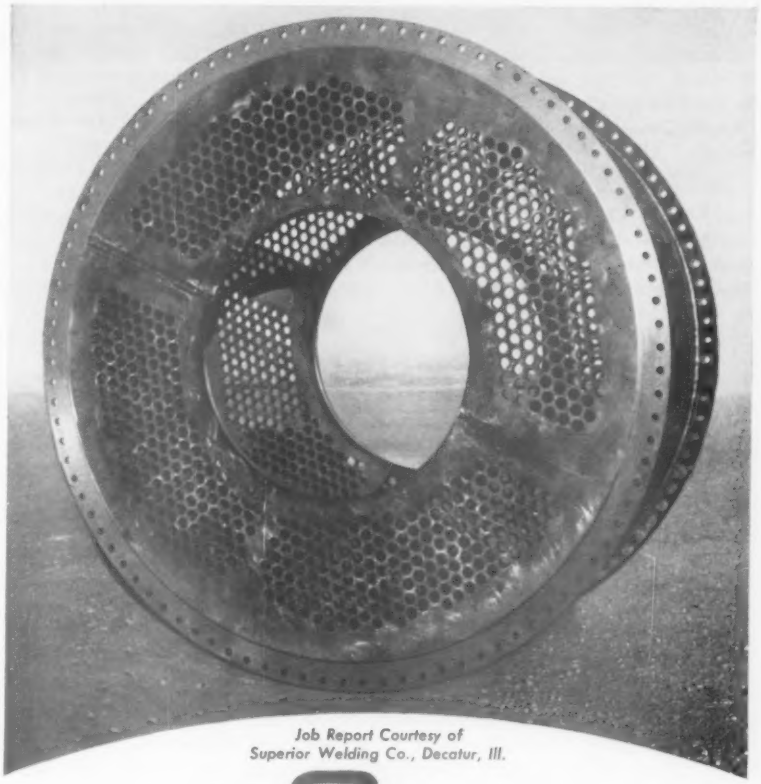
EXECUTIVE COMMITTEE MEETING

Miami, Fla.—The executive committee of the *South Florida* Section met on April 24th, in the offices of the Miami Welding Supply Co.

Acting Secretary Tom Berg stressed the importance of a better meeting place for the coming year. After due discussion, it was agreed to use the new Miami Firemen Benevolent Association's Hall for the coming season.

It was also decided to hold informal meetings on activation of membership and preparation of programs in June, July and August at the new Hall, keeping the third Wednesday of the month as hereto-

How to get trouble-free service from welded stainless equipment



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fore. Regular meetings will resume in September.

ANNUAL SPRING SYMPOSIUM

Grand Rapids, Mich.—The *Western Michigan* Section held its Annual Spring Symposium on Friday, April 12th, at the Morton House in Grand Rapids. There was a registered attendance of 70 for the all-day affair.

The first lecture started at 8:30 A.M. Jerry Hinkel AWS, of the Lincoln Electric Co., Cleveland, Ohio, was the first speaker. His subject was "Selection of Arc Welding Electrodes." His address, illustrated with charts and slides, was very well received.

The second speaker was F. Robert Baysinger AWS, of the Kaiser Aluminum Co. His lecture was on aluminum welding and covered several aspects of aluminum welding in the shipbuilding industry. Slides and a film on shipbuilding in the British Isles were used by Mr. Baysinger.

The first speaker of the afternoon session, which started at 1:30 P.M., was William K. Plummer, president of the Allied Steel Co., Detroit. Mr. Plummer's lecture was on economy in design and production in the resistance welding line and was very ably presented. Slides were used to illustrate Mr. Plummer's talk.

The final lecture for the day was given by Lee H. DeWald AWS, of the National Cylinder Gas Co. Mr. DeWald's talk was on the newest developments in CO_2 welding. He illustrated his talk with slides and two high-speed films. The two films were the latest on the subject and constituted excellent photography.

As in the past, the all-day affair was a complete success and the members are looking forward to next year's event.

An Invitation to Authors

to Participate in

Sixth AWS National Spring Meeting

THE AMERICAN WELDING SOCIETY will hold its Sixth National Spring Technical Meeting and 39th Annual Convention and Meeting at St. Louis, Mo., April 14–18, 1958.

Each year the SOCIETY presents opportunities to Authors for bringing their outstanding work, development and research to the attention of the Membership and the welding and metals industry, by having previously unpresented and unpublished papers presented at its national meetings.

The Society's Technical Papers Committee will be happy to receive applications for entry in the 1958 National Spring Meeting activity in St. Louis, Mo., April 14 through 18, 1958. All applications, abstracts and manuscripts will be screened by the Committee, and Authors will be notified in October 1957 regarding acceptance.

Each abstract should be sufficiently descriptive to give the Committee a clear idea of the content of the proposed paper; in any case, it should contain 500 to 1000 words. (Also, in order to place the Committee in the best possible position to evaluate these papers, it is suggested that each abstract be accompanied by a complete manuscript.)

The Committee reserves the right to consider all applications on the basis of acceptance for placing on the 1958 National Spring Meeting Program, or consideration for placing on the 1959 National Spring Meeting Program, the next National Meeting of the SOCIETY. Papers may be considered for publication in THE WELDING JOURNAL regardless of acceptance for presentation at either Meeting.

Papers dealing with latest developments in (1) fabrication and maintenance of equipment used for radioactive applications, (2) brazing, (3) welding of dissimilar metals, (4) machinery design and fabrication, (5) automation as applied to resistance welding, inert-arc welding and other welding processes, (6) welding of castings and composite structures, (7) welding of plastics, (8) soft soldering, (9) equipment and transmission lines used in petroleum industry, (10) structures and railroads, (11) magnesium, zirconium, molybdenum and like metals and (12) practical applications or "how-to-do" topics are deemed to be of particular interest at the St. Louis meeting. However, any papers dealing with the educational and informative categories of welding production, engineering, research and metallurgy are welcomed as long as the subject falls within the field of our SOCIETY's activities.

To assure consideration for the 1958 National Spring Meeting Program abstracts must reach AWS not later than Aug. 15, 1957. Application forms, if needed, may be obtained by writing to National Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

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Effective as of April 1, 1957

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢, from the Commissioner of Patents, Washington, D. C.

2,777,767—Self-Fluxing Silver Alloy Filler Metal—Theodore I. Leston, New York, N. Y., assignor to Eutectic Welding Alloys Corp., New York, N. Y., a corporation of New York.

The specialized silver-brazing alloy covered by the patent includes specified quantities of silver, copper and zinc and relatively small quantities of manganese, iron and nickel.

2,777,929—Method and Apparatus for Welding Metal Elements—Joseph B. Brennan, Cleveland, Ohio.

Brennan's patent relates to the use of a pair of pressing elements of refractory dielectric material mounted for pressing together metal elements over a portion of their areas. A high-frequency electric current conductor is associated with each pressing element for inducing a heating current in the metal elements to heat them to welding temperature in only an area of the metal elements, while they are subjected to pressure of the dielectric pressing elements.

2,777,936—Making Bimetallic Billet—Laurence J. Berkeley, Danville, Ill., assignor to Superior Steel Corp., Pittsburgh, Pa., a corporation of Virginia.

This patent upon the making of a bimetallic billet includes the steps of disposing a backing component and a facing component in face-to-face relationship with the opposed faces substantially horizontal and disposing members for holding the components together at opposite sides of the backing component. These members have webs in generally vertical positions and flanges at each end thereof and with the flanges being out of firm holding relationship with the facing component. Two masses of flux are provided at different elevations against the outside face of the web of each of the flanged holding members and arcs are progressively drawn from the outside faces of the webs of the flanged members in regions protected from the atmosphere to provide melting zones extending completely through the webs of the flanged members and into the backing component to integrate the flanged members to the backing component. The flanges of these holding members are finally crimped into firm holding relationship with the facing component.

2,777,937—Welding Apparatus—Austin U. Bryant, Berkeley, Calif., assignor to Grove Valve & Regulator Co., Emeryville, Calif., a corporation of California.

This patent relates to circular welding operations on hubs or similar members having circular ends. The apparatus includes a frame and means including tracking wheels for engaging the circular end of the hub for supporting the frame for rotation of the frame about the axis of the hub. Other means drive the tracking means at a constant rate and a welding head is carried by the frame and disposed for circular welding operation between the hub and an adjacent workpiece.

2,777,938—Welding Machine—Werner G. Hess, Dearborn, Mich., assignor, by mesne assignments, to Dana Corp., Toledo, Ohio, a corporation of Virginia.

In this patented welding machine, a welding rod is supported for movement into and out of engagement with the workpiece. A filelike element is provided and means mount such element in the path of movement of the welding rod for movement toward the workpiece to remove the crusted flux from the end of the rod before the end engages the workpiece.

2,777,973—Method and Apparatus for Electric Arc Welding—Richard B. Steele, New Providence, Rawlins E. Purkhiser, Springfield, and Nelson E. Anderson, Berkeley Heights, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

Direct current electric arc welding apparatus is covered in the present patent and it relates to an apparatus including a first transformer secondary winding and a second transformer secondary winding with both secondary windings being energized from the same single-phase, alternating current source and with the first secondary winding having a higher open circuit voltage than the said second secondary winding. Full wave rectifiers connect the two secondary windings in parallel to an electrode and a workpiece. Current limiting means are provided in the higher voltage rectifier circuit to limit the arc current carried therefrom to a minor proportion of the total arc current. Other means cause the output of the two rectifiers to be out of phase by an amount which will provide the voltage between the electrode and the workpiece at all times great enough to maintain the welding arc.

2,778,095—Method of Welding Turbine Blades—Christian Schorner, Augsburg, Germany, assignor to Maschinenfabrik Augsburg-Nurnberg A.G., Augsburg, Germany, a corporation of Germany.

This particular patent is on a specialized welding operation for securing a turbine blade to the rim of a turbine rotor. A groove is provided in the rim of the rotor and an aligning lug is formed at the radially inner end of the blade for interlocking engagement with the groove and the rotor. Thereafter particular welding and machining actions are performed for securing the turbine blades to the rotor.

2,778,099—Method of Welding and Apparatus Therefor—Nelson E. Anderson, Berkeley Heights, and Lawrence M. Layden, New Providence, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

In this new welding method, a weld puddle is established on the workpiece by heat from a welding torch above the workpiece. A filler wire is continuously supplied to the workpiece and with the entire weight of the torch being supported by the filler wire which has a permanent curvature imparted thereto prior to its contact with the workpiece. The filler wire is guided so that it engages the workpiece at the edge of the weld puddle. A portion of the reaction force imposed by the workpiece on the filler wire aids in propelling the torch along the workpiece.

2,778,910—Apparatus for Submerged Arc Welding—George G. Landis, South Euclid, and Harold S. Payne, Cleveland Heights, Ohio, assignors to the Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

This patent relates to electric arc welding apparatus of the type adapted to deposit a pile of granular welding flux on a proposed weld bead and to deposit molten metal simultaneously on such weld bead. A special vacuum control is provided for the welding flux supply so that such control can either prevent welding flux in a hopper from falling out through a discharge passage or to permit the discharge of such weld flux, when an electrode is fed toward the workpiece.

2,778,924—Apparatus and Method for Producing Flat Surfaces—John P. Hill, Detroit, Mich., assignor to Goddard & Goddard Co., Detroit, Mich., a corporation of Michigan.

Hill's patent is on a method of machining a flat surface by electrical discharge. A tubular electrode is provided and it has a plane end surface perpendicular to the electrode axis. This electrode is rotated and traversed relatively of a workpiece across the end of the electrode so that the workpiece moves from a position outside a projected outer surface of the electrode through a position entirely within the projected inner surface of the electrode and back to a position entirely outside the projected outer surface of the electrode

HOW FLASH-BUTT RESISTANCE WELDING IS USED TO FABRICATE PRESSURE VESSELS

Severe test program proves Sciaky techniques of resistance welding provide the safe welds necessary for assembling butane gas containers

In a program undertaken to determine the metallurgical advantages of flash-butt welding for joining half shells of butane gas containers, Sciaky has established the suitability—and superiority—of the process for this application. The flash-butt process offers a 100% strength factor compared to 80% for flame or arc welds.

Job Description

Figure 1 shows the half shell and the assembled container. The metal is deep drawn low carbon steel. The

Fig. 1 At the right is a single half shell. At the left are the half shells joined by flash welding, flash not removed.

half shell has an I.D. of 11.6" and an O.D. of 11.8" or a cross section of 3.63 sq. in.

Special clamps were developed so that the clamping pressure could be applied to a maximum surface of the parts to be welded. End and side views of the clamp arrangement are shown in Figure 2.

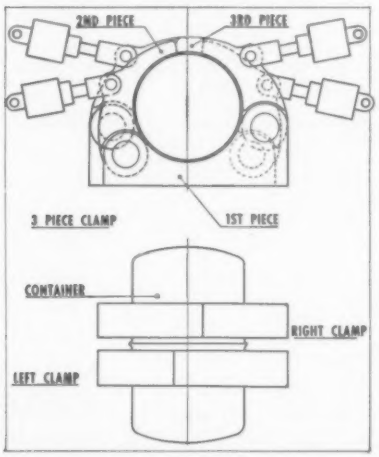

Fig. 2 Clamps for joining half shells.

The welder is a 300 KVA Sciaky Flash-Butt Welder with an upsetting force of 25,000 psi. Current is supplied to both the upper and lower clamping dies in order to assure uniform distribution throughout the diameter. One platen is fixed and the other movable. The flashing system is pneumatically operated and flashing time controlled by an adjustable metering valve.

A wedge cam provides the proper platen acceleration for flashing. A tap switch affords sixteen steps of heat regulation. Copper alloy clamping dies are used as locators and also serve as back-ups for the piece parts during the upsetting.

Test Results

The safety of the flash-butt welds was extensively tested under hydraulic pressure. Two such containers are shown in Figures 3 and 4 and for comparative purposes a fusion welded container in Figure 5.

Extensive metallurgical tests were also conducted from which the following conclusions were drawn:

1. Flash-butt welding makes it possible to obtain a strictly autogenous weld. This is true because the weld is made without the addition of extraneous material, and because the upsetting action displaces the melted base metal and impurities at the weld joint.
2. The flash-butt process makes it possible to obtain a joint having the same consistency on the inside and on the outside of the containers. See the macrographs, Figures 6 and 7.

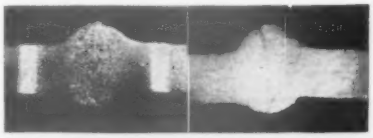

Fig. 6 Macrographs of flash welds before (left) and after annealing. Note consistency on both inside and outside.

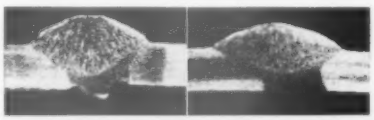

Fig. 7 Macrographs of arc welds before (left) and after annealing. Note irregularities on inside due to lack of penetration of extraneous material.

Complete Report Available

A complete, detailed report with extensive illustrations and the results of additional tests is available without charge. Please write on your company letterhead asking for the *"Engineering Report on Resistance Welding of Butane Gas Containers."* There is no obligation.

Fig. 3 Flash welded and annealed container which burst at 1349 psi. Weld elongation was 29.6%.

Fig. 4 Flash welded and annealed container which burst at 1278 psi. Weld elongation was 24.3%.

Fig. 5 Fusion welded and annealed container which burst at 994 psi. Weld elongation 11.6%.

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NEWS of The Industry

New CO_2 Welding Process Introduced by NCG

A process described as "a completely new development in arc welding, producing faster and better welding at lower cost," was demonstrated recently by National Cylinder Gas Co.

A spokesman for the company said the process, called "Dual Shield," is the first economical and effective combination of flux-cored electrode

Fig. 1 View of equipment and new CO_2 welding process in operation

and shielding gas to achieve low-cost welding of mild steel at a high rate of deposition and travel speed with excellent penetration.

The flux additive, contained in granulated form in the core of the welding wire, includes an ionizer to stabilize the electric arc; a deoxidizer to permit welding mill-run steel without removal of scale and other foreign matter; and a slag-forming agent.

Process successfully uses active carbon dioxide (at one-tenth the cost of inert argon gas) to exclude contaminating air from the arc and to inject a measured portion of oxygen directly into the arc's path where it combines chemically with certain of the flux additives to clean and purify the metal being welded.

This combination of special flux-core electrode and carbon dioxide shielding gas produces a stable arc resulting in well-shaped weld "beads" with deep penetration and practically no wasteful "spatter." A full thickness of a 1/2-in., solid steel plate can be welded in a single pass.

Several advantages are claimed for the process. It is said to allow the welder to have the benefit of flux additives, yet see exactly what he is doing because the flux is inside the electrode. The welder can also work more efficiently and comfortably, as the gun used weighs only 1 1/2 lb. In addition, there is no flux hopper to be refilled.

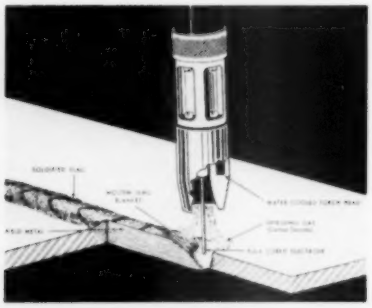


Fig. 2 Diagram shows how process employs inexpensive carbon dioxide gas to exclude contaminating air from the arc and molten metal, as well as to introduce a measured portion of oxygen directly into the weld pool where it combines chemically with certain of the flux additives to clean and purify steel being welded

The new process is described as being three to twelve times faster than manual welding methods, increasing production a conservative 33% over established semiautomatic welding methods. Because of its almost complete elimination of spatter, more than 99% of its weld metal is deposited in the job, compared to 75 or 80% of weld metal deposited by manual welding.

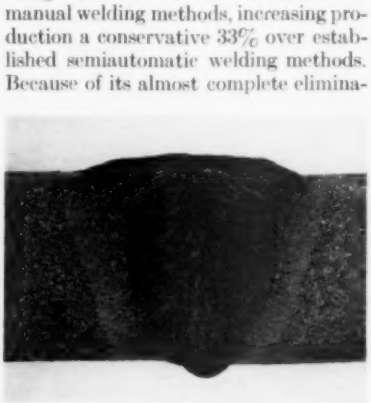


Fig. 3 Butt weld in 5/8-in. mild steel shows unusually deep penetration, smooth bell-shaped bead contour and uniform grain structure

Process is intended primarily for single-pass horizontal and flat welding of mild steels, with or without scale, in thicknesses from 3/32 to 1/2 in. It is said to be unequaled for use where it is advantageous to see the arc and for circular welds of small diameter where difficulty is encountered in holding flux in place.

Equipment includes flux-core electrode in 1/16-, 3/32-, 1/8-, 5/32- and 3/16-in. diam sizes, welding control and wire drive unit and a welding gun.

The new NCG electrode will cost about ten cents a pound more than conventional spool electrodes for submerged-arc welding. But company spokesmen point out that Dual Shield makes up the difference with savings in time, labor, shop space, cost of additional flux, use of inexpensive carbon dioxide and virtual elimination of rejects.

According to manufacturer, process has been field tested for many months with the help of a large tool and die plant and at a heavy-machinery manufacturing plant, both in the Chicago area.

It has also been successfully tested by a Texas manufacturer of gas cylinders and transport trucks, by a Florida manufacturer of oil tanks who discovered that a circumference welding job requiring 35 min with stick electrodes could be done by the new semiautomatic operator in less than half the time, including time to set up and tear down the job, and by others.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1958 Spring Meeting and Welding Show:
April 14–18, Statler Hotel, St. Louis, Mo.

ASM

Nov. 4–8, 1957. Thirty-ninth National Metal Exposition & Congress, concurrently with Second World Metallurgical Congress, International Amphitheatre, Chicago, Ill.

Plant, Research Laboratories and World Headquarters

BETTER ORIGINAL FASTER

Low Temperature EUTECTIC WELDING ALLOYS

STRONGER WELDS

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS CORPORATION, 40-40 172 STREET, FLUSHING 58, NEW YORK, N. Y.

XYRON 2-25 REPAIRS RR DIESEL ENGINE SAVES $10,800, WEEKS OF DOWNTIME

A large break in the first cylinder of a 600 horsepower diesel engine almost resulted in the loss of $10,800 by a Midwestern railroad. Attempts to repair the engine with conventional high heat welding materials failed because the block was thoroughly dirt and oil soaked and its tremendous size made pre-heating impossible.

Fig. 1

The railroad's maintenance foreman was ready to recommend scrapping the engine when Eutectic's District Engineer suggested welding with patented Xyron 2-25, "Eutectic's" newest and most advanced electrode for all types of grey and alloyed cast iron. Xyron 2-25 is usable fast and cold and is the first non-cracking, porosity free, all position electrode for cast iron.

Fig.2

Repair was begun by veeing out all broken surfaces with Eutec-Chamfer-Trode, high speed gouging electrode for all metals. (Fig. 1) Gouging with ChamferTrode provided a good surface for deposits of Xyron 2-25 and burnt out many of the impurities in the casting. After the broken parts were reassembled on the engine block, Xyron 2-25 was used to tack weld. (Fig. 2).

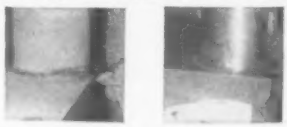
Welding machine was set at 100 amps, DC reversed. The weldor then used a stringer technique with short arc to deposit 2" passes of Xyron 2-25. Peening after each pass relieved stress and slag was easily removed.

Final results were excellent. Xyron 2-25 produced dense, smooth, porosity free deposits at lowest amperages. (Fig. 3) Fast repair with Xyron 2-25 saved railroad $10,800 replacement cost and avoided weeks of downtime. *(A-71)*

HIGHEST STRENGTH JOINTS WITH EUTECTRODE 201

Welded with patented EutecTrode 2101, the aluminum tine joints on this cement block unloader are up to three times stronger than joints of conventional aluminum electrodes. Loads of close to a ton cause the tines to dip as much as eight inches without cracking. EutecTrode 2101 quickly fabricated the block unloader, produced smooth solid deposits with good color match and high resistance to corrosion. The first aluminum electrode with an extruded flux coating, EutecTrode 2101 does not spatter or fume, produces a quiet arc at lowest amperages. EutecTrode 2101 outperforms all conventional aluminum electrodes. *(A-72)*

EUTECTRODE 680 AC-DC AVERTS 10 WEEK STOPPAGE



A Tennessee stamping plant faced an 8-10 week production stoppage because of a cracked shaft on a 340 ton press. Replacement was estimated at $15,000. But downtime was averted and replacement cost saved by using EutecTrode 680 AC-DC and Eutec-ChamferTrode to repair the shaft at a cost of only $37 in materials. Eutec-ChamferTrode, high speed gouging electrode, was first used to vee out the crack, which extended 6" through the 12" shaft. EutecTrode 680, patented high tensile electrode for very high alloy and carbon steels, was then applied. Eutec-Trode 680 welds were applied at lowest amperages. *(A-73)*

In answering industry's requests for technical data, Eutectic's research and engineering staffs help industry save thousands of dollars each year. Your questions, like these below, will be answered without obligation by Eutectic's Technical Information Service.

Q. My company's welding manual makes reference to the use of solder in the repair of lamp socket contacts. EutecRod 157 with Eutector Flux 157 was recommended to us for this application. Will you advise? We would like to incorporate this information in our manual for future use. The fact that this soldering is performed by unskilled personnel should be considered.

A. EutecRod 157 is considered an ideal recommendation. Since this alloy has an extremely narrow plastic range, rapid solidification takes place, assuring a good build-up. It is therefore easier to handle by the unskilled. Deposits are harder and have higher electrical conductivity than conventional solders. This means greater resistances to pitting and general wear. Since the alloy has a higher solidus temperature, the possibility of plasticizing the build-up if accidental arcing occurs is virtually eliminated. Contacts also will remain bright and clean since EutecRod 157 does not contain lead or other elements than darken with age. Melting point is approximately 430° F. Electrical conductivity is 18 percent.

Q. What is the electrical resistance of EutecRods 180, 800, and 1804?

A. Electrical resistivity of all three is almost identical in that values of 23/24 microhms per cubic centimeter are obtained on all tests.

Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, N.Y.

Gentlemen:

I would like further free information on the following:

☐ A-71 ☐ A-72 ☐ A-73

☐ Free 170 page pocket Welding Data Book.

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EUTECTIC WELDING HEADLINES - TIME - MONEY - MACHINERY SAVERS

New Officers at Union Carbide Announced

A. Lyndon Foscue, Birny Mason, Jr., and Edwin B. Suydam were elected vice-presidents and appointed Members of the Appropriations Committee of Union Carbide Corporation it was announced by Morse G. Dial, president of the corporation.

Mr. Foscue has been with Union Carbide since 1924 when he joined Electro Metallurgical Co. at Niagara Falls as a chemist. From there he moved to the Company's plant in Alloy, W. Va., then to New York, in 1948, to fill the position of assistant works manager. He later became works manager, then vice-president and, in 1953, president. He was also appointed president of Haynes Stellite Co. in 1954. Mr. Foscue was graduated from Davidson College, Davidson, N. C., with the degree of Bachelor of Science in Chemistry in 1920.

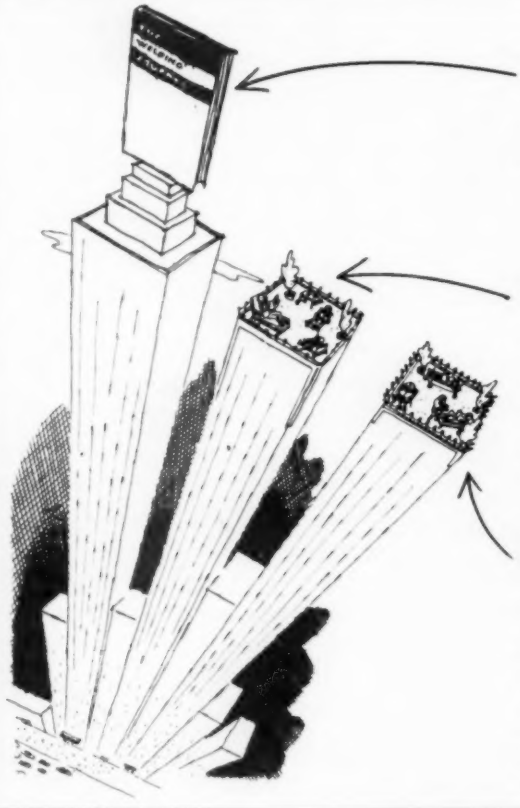
A. Lyndon Foscue

Birny Mason, Jr.

Mr. Mason joined Union Carbide in the Research Department of Carbide and Carbon Chemicals Co., South Charleston, W. Va., in 1932. He held various positions at the South Charleston plant and for two years was assistant superintendent of the Louisville, Ky., plant. He came to New York and, in 1952, became manager of industrial relations for the Corporation. He holds the positions of secretary of the corporation and president of one of its divisions, Union Carbide Development Co. Mr. Mason was graduated from Cornell University in 1931 as a chemical engineer.

Mr. Suydam joined Union Carbide in 1916 as a salesman for Union Carbide Sales Co. in New York. He remained with that company until 1928 when he was made manager of the Southwestern Region of Linde Air Products Co., a division of Union Carbide, with offices in Kansas City. In 1929 he returned to New York. He became vice-president of Linde in 1942 and president in 1955.

Edwin B. Suydam



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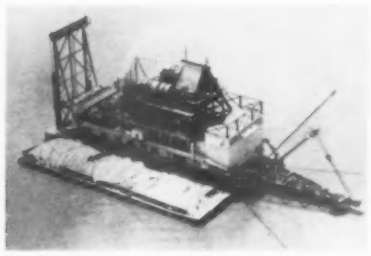
FLOATING FACTORY



Built to operate as a complete plant afloat, the "George F" is truly a dredge with a difference. Operating in Galveston Bay, and rated to move 675 yd of shell per hour, this floating factory—instead of washing and classifying shell ashore—performs these operations on board, thus eliminating a major step in processing.
Horton and Horton, and Brown and Root, Inc., both of Houston, Tex., worked together in the construction of this new queen of Horton and Horton's marine operations, using 30 tons of electrodes, along with oxygen and acetylene for welding and cutting. The dredge can bunk 23 men and is equipped with complete commissary and living quarters. (*Courtesy Air Reduction Sales Co.*)

Alloy Rods Opens Sales Office

Alloy Rods Co., York Pa., manufacturer of welding electrodes, recently announced the opening of a new sales office and warehouse in Houston, Tex. The new facilities are located at 2201 Dallas Ave. in Houston.

The new location is designed to serve company distributors and customers in the southwest.

Dye Oxygen Completes Hydrogen Plant

Dye Oxygen Co. has announced the completion of a hydrogen plant in Phoenix, Ariz. This new plant, engineered and built by Electrolyser Corp., is designed so that it can be expanded easily to take care of future business by adding more cells.

This is the first hydrogen plant to be operated in Arizona, and it will serve this state and southern Nevada.

Weldrod Distributor Appointed

The Weldrod Department of Ampco Metal, Inc., Milwaukee, Wis., announces the appointment of Oxygen Service Co., 349 Market St., Kingsport, Tenn., as a stocking distributor for Ampco Bronze Weldrod Products in the Kingsport sales area.

Appointments Announced by Pureco

J. J. Staudinger has been named to the post of assistant regional distribution manager, central region, it was announced by E. M. Newton, Jr., regional manager, Pure Carbonic Co.

Mr. Staudinger, who will now be located in Cleveland, was former Pureco warehouse manager at Detroit and has been succeeded by J. W. Harr.

T. J. Rochford has been appointed warehouse manager at Cleveland succeeding Mr. Harr.

Resistance-Welding Equipment Shipments on the Increase

Statistics compiled by the Resistance Welder Manufacturers' Assn. for the month of March indicate that shipments for that month have increased nearly 40% over February shipments.

March shipments again considerably exceeded $3 million, making this the seventh month out of the last nine when this figure has been reached.

Members continue to report a high backlog—nearly $13½ million at the end of March.

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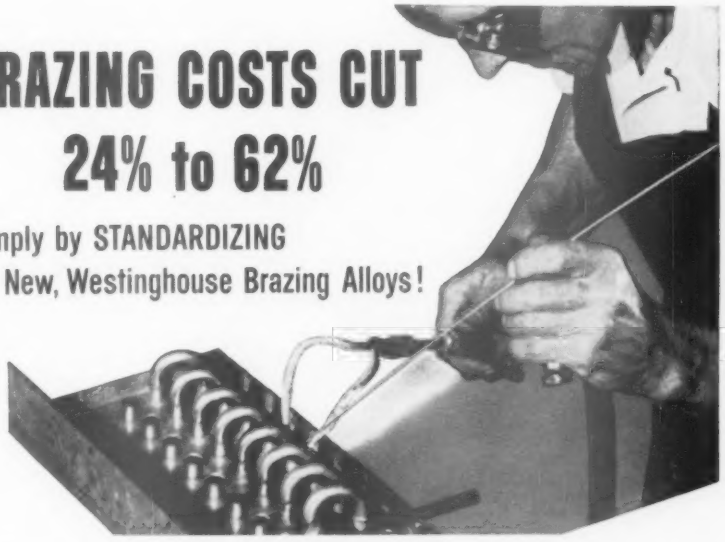

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Convenient packaging, 18" lengths, 1-lb and 5-lb tubes. Standard 25-lb package, 36" lengths. SAME ALLOYS AVAILABLE IN ROD FORM—WIRE IN COILS—or in rings!

YOU CAN BE SURE...IF IT'S Westinghouse

Tenth Western Metal Congress Held in Los Angeles

Officially clocked attendance at the 10th Western Metal Exposition which ended a five-day run March 29th in the Pan-Pacific Auditorium, Los Angeles, set an all-time high figure of 73,858.

Mainly the throng consisted of plant operators and metal engineers seeking latest information on developments to step up their activities and reduce costs.

The Los Angeles show covered 184,800 sq ft of floor area, and had 420 exhibiting firms in more than 350 displays.

Sessions of the accompanying Los Angeles Metal Congress in the Ambassador Hotel had heavier attendance than at any other time in the convention's history.

Meetings were held by American Society for Metals, AMERICAN WELDING SOCIETY, Society for Nondestructive Testing, Industrial Heating Equipment Association and Metals Branch—American Institute of Mining, Metallurgical and Petroleum Engineers.

In addition, ASM's Metals Engineering Institute presented a five-day Titanium Conference, which had an attendance exceeding expectations.

Huron Site of New Eutectic Warehouse

A new Eutectic Welding Alloys Corp. Warehouse-Service Center opened in Huron, S. Dak., on February 5th, according to a recent statement by President Rene D. Wasserman.

This new Warehouse-Service Center, is located at 358 Wisconsin Ave., S. W.

Judges Selected for Steel Welding Competition

Donald S. Clark, president of the American Society for Metals, has announced the names of the four welding authorities who will serve with him in judging entries in the first annual $1500.00 Gregory Award Competition for the most significant contribution in the field of stud welding. They are: William H. Schuster, supervisor of welding, American Car & Foundry Div., ACF Industries, Inc., New York, N. Y., J. H. Weigel, general manager, St. Louis Div., Combustion Engineering, Inc., St Louis, Missouri; Dr. Robert D. Stout, Head of the Department of Metallurgy, Lehigh University, Bethlehem, Pa.; and T. J. Griffin, head civilian, welding, Casting and Fabrication Branch, Department of the Navy, Bureau of Ships, Washington, D. C.

The deadline for entries in the competition is midnight June 30, 1957. The award will be presented at the 1957 Award Luncheon of the American Society for Metals in Chicago Nov. 5, 1957.

Information on the competition may be obtained from Gregory Industries, Inc., Lorain, Ohio, manufacturers of Nelson stud welding equipment, or from the American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio.

Distributor Named by Westinghouse

Westlake Electronic Supply, 509 Westlake Ave., North, Seattle 9, Wash., has been appointed a distributor of Westinghouse Reliatron® tubes. The announcement was made by Louis Martin, sales manager for the Westinghouse Electronic Tube Division, Elmira, N. Y. The Seattle firm serves Seattle and King County, Wash.

The firm will handle the full line of Reliatron tubes, including receiving, cathode-ray and industrial tubes.

Wall Colmonoy Appoints Chicago Representative

Appointment of Walter W. Rogers as sales engineer for the company's Chicago district sales office has been announced by William P. Clark, vice-president of Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

In his new position, Mr. Rogers will operate in Illinois, southern Wisconsin and northern Indiana. Chicago offices for Wall Colmonoy are located at 4806 W. Chicago Ave.

A graduate of Industrial Engineering College in Chicago, Mr. Rogers has had broad industrial experience in the production, service and sales engineering fields. His previous positions have included those of production manager for Mid Western Die Casting, national service manager for Cory Corp. and sales engineer for a metallizing firm. The latter position was held prior to joining Wall Colmonoy.

Airco Appoints Meyer Branch Manager

The Chicago district of the Air Reduction Sales Co. has been expanded to include the Bettendorf, Iowa, area. Fred G. Meyer, assistant sales manager, has been named branch manager at Bettendorf, it was announced by D. D. Spoor, regional vice-president.

A salesman with the company since 1928, Mr. Meyer became assistant sales manager in 1945 and was appointed to the new post earlier this year.

Wear Your AWS Emblem

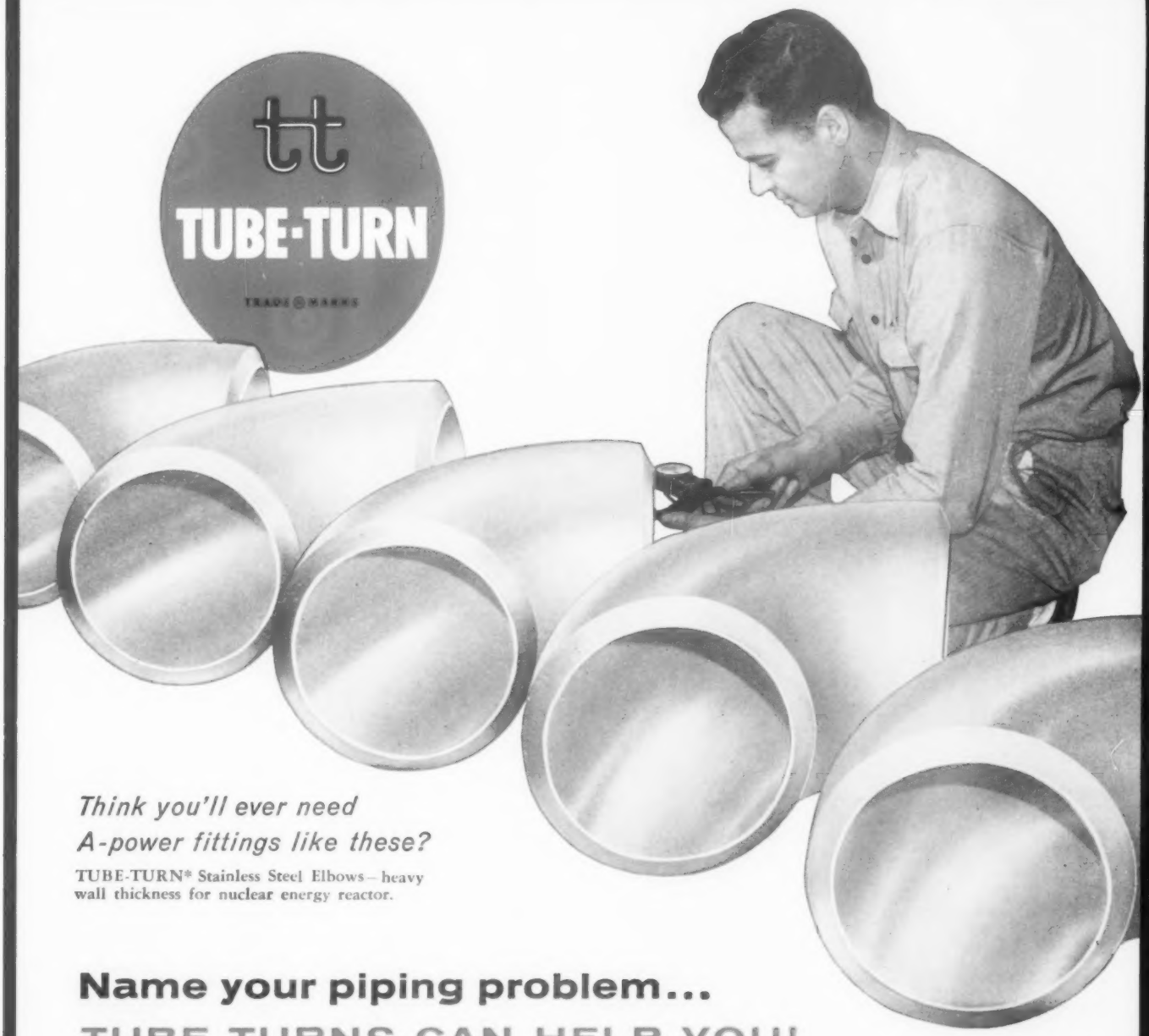
Lincoln Starts Plant Addition

The Lincoln Electric Co. in Cleveland began in April to put up the first steel work for an $8,500,000 addition to its five-year-old, 20-acre floor area plant. Capacity is being added to both the electrode and machine divisions. The new building will have under roof, on one floor, almost 30 acres. The new production facilities,

it is expected, will improve the supply position of the welding industry, since it will include both storage and manufacturing space. It will also enable Lincoln to supply its 34 warehouses which it has been acquiring in principal cities throughout the country. The Austin Co. are the engineers and builders of the plant and its new addition.

EUROPEAN VISITOR

Dr. G. M. Blanc, associated with Société des Soudures Castolin, S.A., Lausanne, Switzerland, recently made a speaking tour of the United States and Canada. He is pictured above (*extreme left*) at Adams National Meeting in Philadelphia, with AWS President-Elect C. P. Sander; Rene D. Wasserman, president of Eutectic Welding Alloys Corp.; and AWS Past-President Fred R. Plummer



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A-power fittings like these?

TUBE-TURN* Stainless Steel Elbows—heavy wall thickness for nuclear energy reactor.

Name your piping problem...
TUBE TURNS CAN HELP YOU!

No matter what kind of welded piping system you build . . . here's how Tube Turns can be of help:

Tube Turns' line includes 12,000 *standard* welding fittings and flanges, plus thousands of *specials* such as the A-power fittings shown above. When you buy from this *complete-line* leader, you get what you need *promptly* . . . products of unsurpassed *quality* . . . backed by experienced *engineering service* . . . for reliable, *low-cost piping.* Order from your nearby Tube Turns' Distributor.

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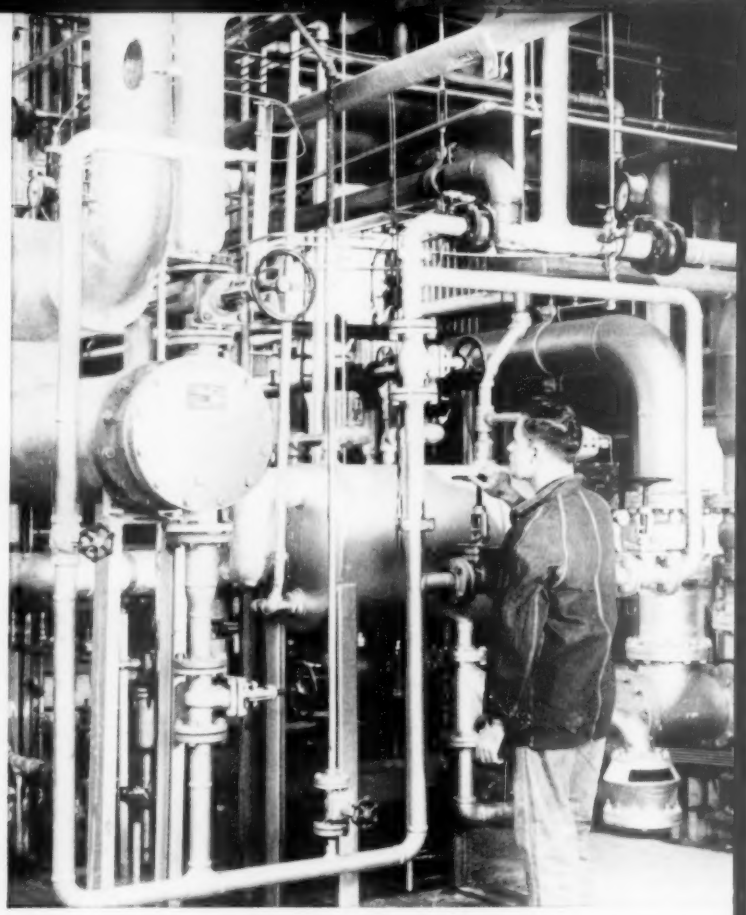
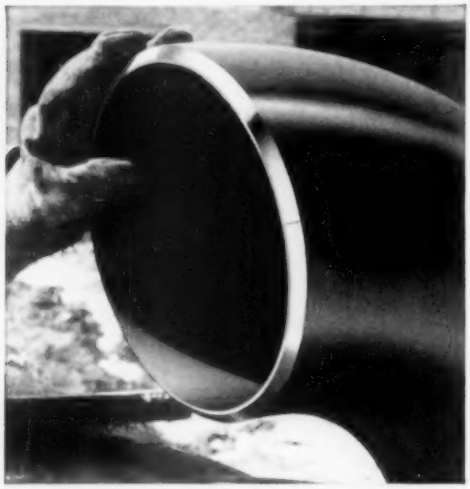
12,000 "TUBE-TURN" PRODUCTS

to help you save 3 ways...



SIMPLIFIES ENGINEERING. There's no compromise when you specify TUBE-TURN products. You can count on getting the exact fittings for your project ...the right type, size, schedule and material for every piping service. Shown at right: Aluminum piping with TUBE-TURN Welding Fittings and Flanges, in water purification plant of The General Tire & Rubber Company, Chemical Division, Ashtabula, Ohio.



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HELPFUL DATA. New Tube Turns' booklet gives information on pipe, fitting and flange materials. Mail coupon for your free copy.

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PERSONNEL

Strother Joins Alloy Rods

E. R. Walsh III, vice-president in charge of sales, Alloy Rods Co., York, Pa., recently announced the appointment of John Strother to the company sales organization.

Mr. Strother was graduated from Poncelot Institute of Technology, Charlotte, N. C., where he was awarded his degree in Civil Engineering in 1936.

John Strother

Following his graduation, he held several engineering positions concerned with welding applications and processes. Later he turned his talents to the sale of welding equipment and supplies and now joins Alloy Rods Co. to work with their distributors in the Southeastern States area.

Kiernan, De Santo and Delbridge Appointed by M&T

R. T. Brown, sales manager of Metal & Thermit Corp.'s Welding Division has announced the following changes in organization, effective April 15, 1957:

N. F. Kiernan assumes the post of regional manager for welding products in the West Central Region with headquarters at the company's sales office in East Chicago, Ind. Mr. Kiernan joined M&T in 1938 as a research test welder and since 1955 has been regional manager of its Northeastern Region operating first from Newark, N. J., and more recently from the company's new General Offices at Rahway, N. J.

J. DeSanto, who has served as acting regional manager at East Chicago for the past two years is undertaking additional field sales responsibilities in the Chicago area.

C. F. Delbridge succeeds Mr. Kiernan as regional manager in the Northeastern area and will have offices at Rahway, N. J. Mr. Delbridge, who joined M&T in 1954, was previously assistant to the president of Superior Industrial Gases and general manager of American Gas & Chemical Corp.

The Messrs. Kiernan, DeSanto and Delbridge are members of the AMERICAN WELDING SOCIETY.

Boberg Elected Vice-President

I. E. Boberg, Chief Engineer of the Chicago Bridge & Iron Co., Chicago, Ill., has been elected a vice-president of the company.

Mr. Boberg, who is a graduate of the University of Illinois, joined CB&I in 1924. In 1927 he left to work in the consulting field, returning to the company's Chicago engineering department, and from 1935 until 1941 served as assistant to the chief engineer. During World War II, Mr. Boberg was in charge of all engineering and construction of floating drydocks at the company's Morgan City, Louisiana, Yard. He has been chief engineer of CB&I since 1945.

Mr. Boberg is a member of the AMERICAN WELDING SOCIETY, American Society of Civil Engineers, American Society for Testing Materials and the National Association of Corrosion Engineers, and is active on a number of their committees, and committees of the American Petroleum Institute and the Welding Research Council. In the latter, he is a member of the main committee and executive committee of the Pressure Vessel Research Committee, and Chairman of the Fabrication Division. He is a member of honorary societies Tau Beta Pi, Sigma Tau and Chi Epsilon.

Corcoran Appointed

The appointment of Richard E. Corcoran to the newly created position of product sales manager of wire and weld products for the Parts Division of Sylvania Electric Products, Inc., has been announced by Philip M. Pritchard, divisional general sales manager.

Mr. Corcoran, with headquarters in Warren, Pa., will be responsible for sales of wire and weld products manufactured at Sylvania's plants in Warren and Nelsonville, Ohio. Prior to this new assignment, Mr. Corcoran has been sales engineer of wire and weld operations, which include plating and carbonizing.

Mr. Corcoran joined Sylvania in 1951. He was previously with the Battelle Memorial Institute in Columbus, Ohio, and the National Cash Register Co. in Dayton.

He is a graduate of Bowling Green State University in Bowling Green, Ohio.

Adkins Joins Kaiser

Howard E. Adkins recently resigned as an assistant professor of Industrial Processes in Mechanical Engineering at the University of Wisconsin, and joined Kaiser Aluminum and Chemical Sales, Chicago, Ill., as a welding specialist in the field engineering group.

Mr. Adkins taught welding at the

Howard E. Adkins

University of Wisconsin for ten years. Prior to that, he taught five years for the War Department.

He helped to organize the Madison AMERICAN WELDING SOCIETY Section, serving as its chairman last year. He received the Meritorious Award at the 1957 Adams National Meeting in Philadelphia.

Hickey Appointed Sales Manager

Thomas A. Hickey has been appointed sales manager of the K-G Equipment Co., a division of Air Products, Inc., Allentown, Pa., it has been announced by Karl Schmuldt, vice-president. Mr. Hickey has been regional sales manager since last year.

Prevas Promoted

Peter J. Prevas has been named to the post of assistant plant superintendent of Arcrods Corp., Sparrows Point, Md., it was announced by W. Brainard, president.

Mr. Prevas, with Arcrods since 1946, formerly held the position of process engineer, being primarily concerned with the development of chemical manufacturing specifications for welding electrode coatings.

Mr. Prevas has a B.A. degree (chemistry major) from Johns Hopkins and did graduate work at the University of Maryland. He currently teaches chemistry to evening classes at Baltimore City College. He is a member of the American Chemical Society and the AMERICAN WELDING SOCIETY.

Barckhoff and Nangle Named

Jack R. Barckhoff and David J. Nangle have joined The Lincoln Electric Co.'s district offices at Minneapolis, Minn., and Union, N. J., respectively. Mr. Barckhoff is a native of Columbus, Ohio, where he attended local schools and Ohio State University. He worked as a tool and die designer and served two years as an artillery officer in the United States Army before he joined Lincoln.

Mr. Nangle is a Bostonian. After graduating from Holy Cross in 1953 with a degree in Industrial Relations, Sales and Statistics, he was a United States Marine Corps officer for two years. Both men spent a year in training at Lincoln's plant in Cleveland before joining the district offices.

Canfield Made Assistant Sales Manager

Lloyd L. McBurney, president of Smith Welding Equipment Corp., Minneapolis, has announced that Norwood N. Canfield, formerly district sales manager as well as advertising and promotion manager, has been advanced to assistant sales manager under W. H. Fulton, general sales manager, and will take over the administration of all inside selling functions.

Norwood N. Canfield

Mr. Canfield's duties will include supervision of the Service Department, sales correspondence communications and advertising, as well as assistant in planning, programming, implementing, and coordinating the over-all sales program.

Whitley Appointed District Manager

The Southern Oxygen Co. announces the appointment of W. W. Whitley as district manager of the Southern Oxygen Atlanta office. Formerly only a medical supply outlet, the Atlanta district office now has entered the welding equipment and supplies field, covering Georgia, South Carolina and northern Florida.

Mr. Whitley comes to the Atlanta office with an extensive background in welding and sales. For the past 8 years he has been a welding sales engineer located in the company's Philadelphia district office. He learned welding in 1935 by completing his apprenticeship at Newport News Ship-

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Hot Dip Aluminizing Process

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W. W. Whitley

building & Dry Dock Co. He took an evening course in welding engineering at Massachusetts Institute of Technology and also took the welding metallurgy course at Temple University in Philadelphia. He was with New York Shipbuilding Corp. for six years before coming to Southern Oxygen Co. in 1948.

He has been active in the AMERICAN WELDING SOCIETY, having served three years on the local board of directors as publicity chairman.

Perkins Promoted

C. D. L. Perkins, sales assistant for Air Reduction Sales Co. in the Philadelphia District, has been appointed assistant sales manager of that district,

C. D. L. Perkins

it was announced by A. S. Blodget, Jr., regional sales manager.

Mr. Perkins joined the company in 1950 at Charlotte. He represented Airco in Charlotte, Richmond and Louisville as a salesman before becoming sales assistant in the Philadelphia district in 1955.

ABSTRACT DEADLINE FOR
1958 SPRING MEETING
AUGUST 15, 1957

OBITUARY

Lew Gilbert

Lew Gilbert, who only recently was named publishing director of *Industry*

Lew Gilbert

& Welding Magazine and *Welding Illustrated*, died on April 12th at Mt. Sinai Hospital, Cleveland. He was 47 years old.

Mr. Gilbert first joined the magazines in 1949 as an associate editor. Since that time he served as editor, executive editor and general manager before being named to his most recent post in February of this year. He was acknowledged as one of the nation's leading authorities on the welding processes, welding equipment and supplies, and was a national director of the AMERICAN WELDING SOCIETY.

Prior to joining the magazines, he was engaged in research and development of welding electrodes with Metal & Thermit Corp., New York; welding engineering at M. W. Kellogg, Jersey City; and technical sales for Champion Rivet Co., Cleveland.

Heartfelt Condolences

We, the Editors of THE WELDING JOURNAL, *extend our sincere and heartfelt condolences to the bereaved family of our fellow Editor, Lew Gilbert. Lew loved all things of welding and his tireless efforts on behalf of our industry have left an imprint which time will not erase. We will miss him!*

THE EDITORS

AT THE FRONTIERS OF PROGRESS YOU'LL FIND

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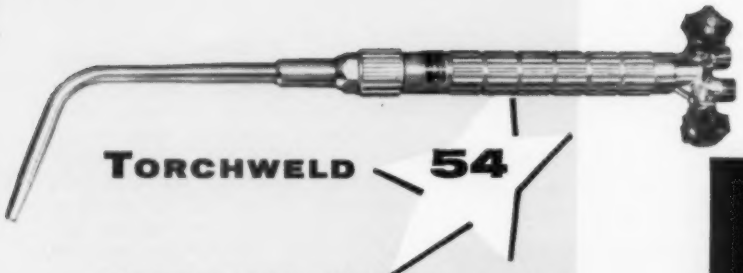
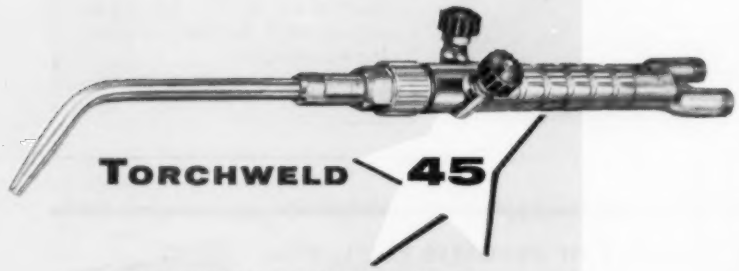


THE WIDE-RANGE, ALL-PURPOSE WELDING TORCH

This is the torch *par excellence* for all types of work, from 28 gauge sheets to 1" slabs or more. Has easy-adjustment non-seizing valve mechanism for precise control of gas pressure and flow. Mixer blends gas perfectly, delivers to tip without restriction. Both swaged and drilled tips are available to provide required flame characteristics.

Rugged, tough stainless steel tubes . . . silver-brazed at head and base. Lightweight, strong brass handle, grooved to give sure grip and control. Mixer has buna seating rings for leakproof hand-tightening. No metal-to-metal contacts. No scratching or scoring. No costly reseating of torchhead.



THE LIGHT AND MEDIUM DUTY WELDING TORCH

For automotive welding, pipe welding, sheet metal fabrication, steam-fitting, etc. Aluminum handle, lightweight but rugged. Valve wheels placed conveniently at front end, under the thumb. Mixer delivers perfectly mixed gases. Mixer has buna seating rings for leakproof hand-tightening.

FAMOUS BANTAM® WELDING TORCH

Ideal for welding aluminum, alloys, aircraft tubing, steel from 28 gauge to ⅜" thick. Lightweight, easy to handle, compact for use in tight quarters.

Valve wheels placed conveniently at front end, under operator's thumb. Special nickel alloy tubes, silver-brazed at head and body. Non-seizing, non-scoring stainless steel valve stems. Mixer designed for perfect gas mixing.

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The All-Star Line of Welding and Cutting Equipment

In this outstanding line of regulators, torches, tips and accessories you will find features galore. Operating features that boost production, handling features your operators go for: cost-cutting features, durability and dependability. All backed by a great manufacturing and engineering organization and a nation-wide network of dealers offering prompt service in every respect. Ask your nearest authorized NCG dealer or NCG office for a demonstration. Or write for a complete catalog.

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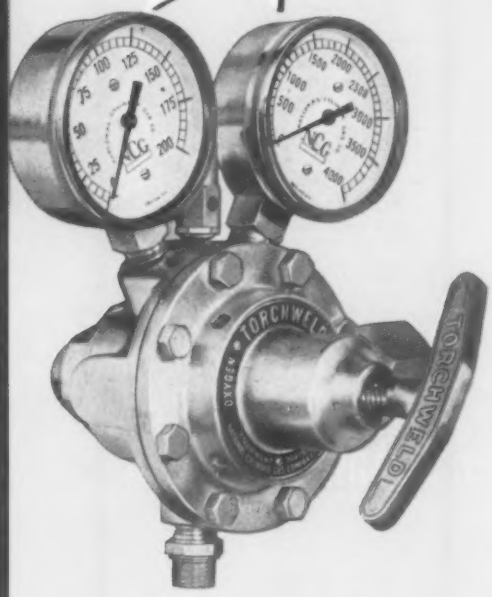
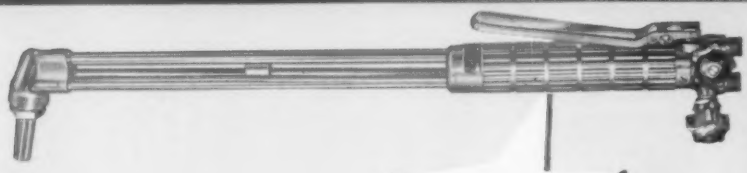
TORCHWELD 6500 Regulators



TWO STAGE PERFORMANCE AT SINGLE STAGE COST

The best features of both types of regulators—the *dis*advantages of neither . . . that's what you get in the 6500 Series Regulators. That's because of the patented pressure compensating chamber. It maintains desired set pressure *throughout the usable cylinder range!* Yes, here's simple construction, low initial cost, and the precise control of pressures and volumes found elsewhere only in the more expensive two stage regulators.



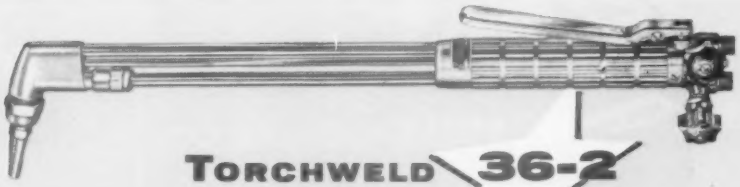
TORCHWELD 75-1

THE OUTSTANDING CUTTING TORCH

This is the ideal performer for operations of any size or any kind, from small shop to huge mill. Cuts sections up to 16 inches thick.

Pressure-forged, rugged brass valve body; non-seizing stainless steel needle valve stems. Non-warping forged bronze or abuse-resistant nickel alloy heads. Nickel-alloy tubes, set in self-reinforcing triangular formation. Silver-brazed into handle and head. Precision-swaged tip orifices for perfect gas flow and clean, sharp kerfs.

Long control lever, equipped with exclusive *packless* valve. Gives positive smooth control even at lowest rates of flow. Pre-heat gases are blended in tip.



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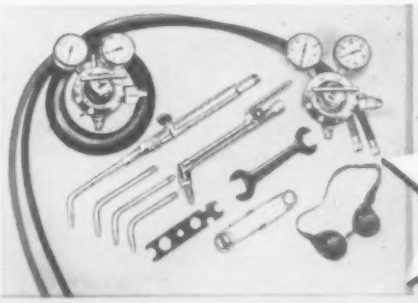
SPECIAL CUTTING TORCH FOR WIDE RANGE OF GASES

A medium pressure pre-mix type cutting torch designed for use with propane, butane, natural gas and city gas as well as acetylene. A fast economical cutter, its capacity ranges up to 16 inch sections.

Top or bottom lever, 75° or 90° forged bronze head. New packless type valve, far outlasts conventional types. Better control and smoother flow of cutting oxygen. Universal type silicon-bronze mixer. Precisely blends preheat gases through entire range of tip sizes. Nickel-alloy tubes, silver-brazed to head and body. Rugged, heavy-duty brass handle, grooved for sure grip and control.

SOD-R-BRAZE® ACETYLENE-AIR TORCH

An efficient, economical soldering, heating and light brazing torch . . . perfect for plumbing, refrigeration, automotive, electrical, maintenance and repair work. Three-way thumb control. Operator turns on and off, adjusts flame and sets pilot light—all with a flip of the thumb. Tips have individual mixers. 6 different sizes for a wide range of work.



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A wide range of ready-to-use complete outfits for every welding and cutting need in every type of shop or plant. All needed accessories are included. Outfits cost less than the total price of components when bought separately.

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Cutting attachments are available to convert each welding torch into an efficient, highly productive cutting torch. Doubles the usefulness of your welding torch.

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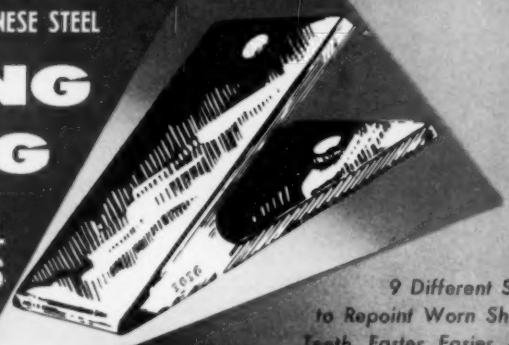

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Welding section of Manufacturing Research & Process Department has an excellent opportunity for a college graduate with BS in engineering or science, plus 3 years experience in welding. The applicant selected will conduct research and development programs in welding; also act as welding consultant to engineering, and apply welding processes for production. Experience in aircraft manufacturing preferred.

Salary commensurate with experience and ability to work with high degree of independence.

Among other advantages, Republic offers a comprehensive benefit program including company-paid hospitalization, surgical, accident and life insurance, tuition (⅔), 2-fold pension plan, individual merit rated increases and many other benefits.

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Position Vacant

V-343. Engineer. Age 28 to 33, with experience in the gas welding, cutting and pressure regulator fields to assume duties as assistant chief engineer in the design of new products and the development of new manufacturing processes.

Established, growing Cleveland manufacturer of gas welding and cutting equipment. Send complete résumé indicating salary desired.

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Assistant to Executive Vice-President. Sought—a relatively young, ambitious man, with a metallurgical background, and who preferably has some experience in the ferro-alloy fields. We are consulting management engineers. Our client is a large, nationally known, progressive, growing corporation which produces ferro-alloy products. This man will work directly under the executive vice-president in New York City. His duties will be varied—sales and sales promotion, technical service, and main office to plant liaison, etc.

Compensation is open to negotiation, based upon a man's experience and capabilities. Liberal salary plus management bonus. There is great opportunity here for a man to make further personal progress. Inquiries will be handled in strict confidence, and without any obligation. Weston Richardson & Associates, 6 E. 44th St., New York 16, N. Y.

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Sales Engineer to obtain customers for contract welding and engineering services, who have continuing requirements for welded steel fabrications (maximum 30 tons). Must be alert to customers' planning as it affects weldment purchases. Must have basic engineering training or experience, knowledge of plate steel fabrication, and successful industrial sales experience. The initial sales territory is the Cleveland and Akron Industrial areas in Ohio.

Forward inquiries or applications to the Personnel Department of Lewis Welding & Engineering Corp., 1 Interstate St., Bedford, Ohio.

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2 RESEARCH METALLURGISTS

Masters or Ph.D. degrees preferred. 25 to 35 years of age. Work in applied research, dealing with welding of ferrous and non-ferrous alloys, investigation of service problems, and selection of materials of construction.

Applicants should have experience in the application of metallurgy to production problems.

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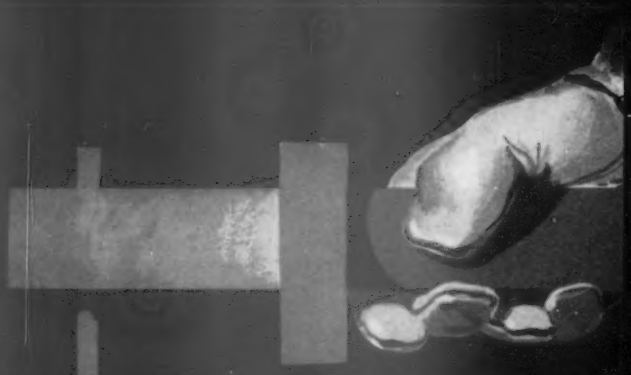
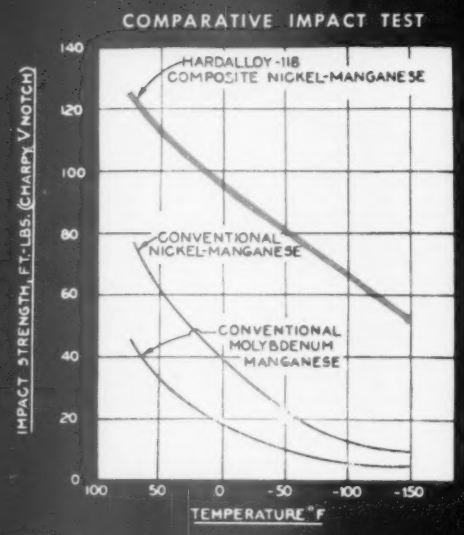


McKAY

HARDALLOY 118

NICKEL-MANGANESE ELECTRODE



The Nickel Manganese Weld Deposit that takes a 180° Bend!

McKay Hardalloy 118, a composite Nickel-Manganese Electrode, combines *all* the properties of nickel-manganese electrodes—and more!

- **Greater Crack Resistance**
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For a Nickel-Manganese Electrode that deposits an extremely tough, wear-resistant alloy that can be used for build-up and *safe* joining of austenitic manganese or manganese to mild—get the full story about McKay Hardalloy 118 Low Hydrogen Electrodes.

Send for literature on McKay Hardalloy 118

HERE IS PROOF!

Test Specimen—½" Austenitic Manganese Plate Double V Joint

Unretouched photograph of bend specimen welded with Hardalloy 118 shows a full 180° bend without fissures or cracks appearing at the weld joint or in the deposited metal.

THE McKAY COMPANY 1005 Liberty Avenue, Pittsburgh, Pa.

NEW LITERATURE

Pipe Welding

Developments in welding of steam-power piping are described in "Welding Chrome-Moly Alloy-Steel Piping," an 8-page reprint of a *Power* magazine article written by I. H. Carlson and E. J. Hemzy, Crane Co. Copies are available from Linde Co., a Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y. Ask for Booklet F-1055.

Design Manual

Tips for design engineers on how to take full advantage of the inherent savings possible with stud welding are among the features of a new 24-page Design Manual now available from the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

The manual contains full descriptions and physical properties of the various stud types, including the new standard "CP" stud which is recommended for the large majority of applications where a straight threaded stud is required. Manual sections of special interest for designers are those discussing stud selection, counterbore and countersink dimensions for accommodating weld fillets, recommended thicknesses of steel on which studs are welded, and stud locating procedures including template design.

Symposium on Solder

Soldering is one metallurgical operation that is probably known better and practiced by more people than any other. However, the simplicity and ease of applying soft solder can be very misleading, for the problems of soldering actually involve several branches of science including chemistry, physics and metallurgy.

The 16 papers comprising this Symposium explore these fields in detail. They illustrate the vital role of fluxes, solder compositions and applications in attaining satisfactory service performance of soldered joints. This Symposium covers the manual, mechanized, and ultrasonic techniques of soldering and at the same time emphasizes the role of standardization in solder technology. A unique system is presented for evaluating fluxes, solder alloys and solderability in numerical terms.

The Symposium was sponsored by ASTM Committee B-2 on Non-Ferrous Metals and Alloys. Copies of ASTM Special Technical Publication 189 may be obtained from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $3.00 each.

Resistance Welding Control

Bulletin GEA-6408, 12 pages, describes new line of nonsynchronous resistance welding controls, discusses variety of available combinations, lists typical applications, explains use of plug-in control units and ignitron contactors, lists features, and provides dimensions of various contactor and control enclosure combinations—Write to General Electric Co., Schenectady 5, N. Y., for your copy.

Ampco Welding News

The First Quarter 1957 issue of the *Ampco Welding News*, published by the Weldrod Department of Ampco Metal, Inc., was recently released for distribution.

This issue contains several very interesting articles pertaining to savings which can be made through the use of bronze electrodes and filler rods.

Free copies of this publication may be obtained by writing to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Brazing Rings

A new 2-color illustrated Engineering Data Sheet (No. 19) describing new Nicrobraz brazing rings for stainless and high-alloy steel tube assembly work is now available from Stainless Processing Division, Wall Colmonoy Corp., 19345 John R, Detroit 3, Mich.

The new data sheet describes features and advantages of the rings and discusses their application. Available alloy grades for the full range of Nicrobraz rings are indicated and their characteristics and physical properties outlined. Photos showing a typical component of tubular construction during ring assembly and following brazing are included.

Industrial Gas Equipment

Industrial gas manifolds with automatic controls are described in a new 24-page Oxweld catalog now available from Linde Co., Division of Union Carbide Corp. Acetylene generators capable of delivering from 100 to 9000 cu ft of acetylene per hour are also included. Recommended uses and specifications are given for a complete selection of equipment for gas piping systems, including hydraulic back-pressure valves of all types, relief valves, station valves, oxygen filters and station check valves.

Copies of the new catalog may be obtained from the Linde Co., 30 E. 42nd St., New York 17, N. Y. Ask for Form 4486—Oxweld Catalog Section 4.

Selector Chart

A new Selec-Tic Wall Chart designed to help welders choose welding alloys for maintenance and production jobs is available free from Technical Information Service, Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing, N. Y.

Recommendations are made for EutecRods and EutecTrodes designed to overcome welding problems on cast iron, aluminum, steel, copper and other base metals.

DESIGN PAPERS

Papers dealing with the progress of welding in the fields of *structural design* and *machine design* are solicited for the 1958 AWS National Spring Meeting in St. Louis, Mo. For proper consideration, manuscripts or 500-word abstracts, must reach AWS Headquarters prior to August 15, 1957.

A. O. Smith developed the exclusive techniques and machines for making non-corrosive "lined" pressure vessels for use in oil refineries, pulp digesters and chemical plants. The non-corrosive liners are spot welded to the inside of the vessel with thousands of welds.

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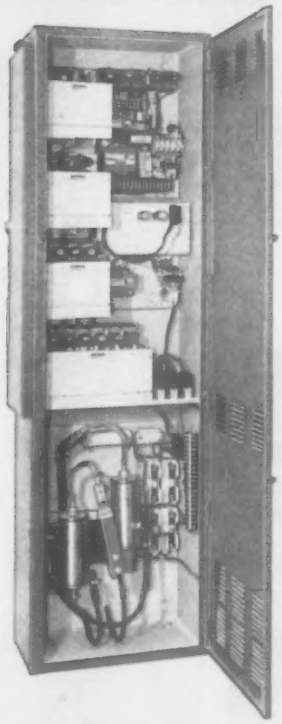

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The new chart also gives the welder bonding temperatures, tensile strengths possible and Rockwell hardnesses.

Copies of the Selec-Tie Wall Chart are also available free from Eutectic District Engineers and from Eutectic Warehouse Service Centers in Atlanta, Chicago, Dallas, Berkeley, Huron and Phoenix.

Resistance-Welding Control

Bulletin GEA-6593, four pages, describes nonsynchronous resistance welding control for special combination control or single- or multielectrode welding machines, and for sequence control of automated machines; lists features; provides description, operation and typical applications of the control. Write to General Electric Co., Schenectady 5, N. Y., for your copy.

REVIEWS

OF NEW BOOKS

Prevention of Brittle Failure

Control of Steel Construction to Avoid Brittle Failure, cloth-bound book, simulated leather, 184 pages, copiously illustrated and indexed. Prepared by a Committee of the Welding Research Council. Price $4.50. Distributed by AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Edited by M. E. Shank, Massachusetts Institute of Technology.

For several years, the Plasticity Committee of the Welding Research Council has been working on the preparation of a manual which would analyze researches dealing with the notch sensitive properties of structural steel and summarize available information and data of significance in design and construction.

The volume is divided into three parts: Part I. *Materials*—presents the basic concepts and mechanisms of notch brittleness, and discusses the pertinent mechanical and metallurgical factors which affect adversely the local plastic behavior of structural materials. Where practicable, the effects of various factors are presented in either summary form or graphically. Where data are inconclusive and concise presentation is not possible, an effort is made to delineate the boundaries of available knowledge.

Part II. *Fabrication*—deals with fabrication of structural components. How conventional fabrication procedures affect notch ductility of structural materials is explained.

Part III. *Design*—attempts to integrate the information contained in the first two parts of the book with a view to aiding the designer in selecting and specifying the best suited materials and fabricating procedures. In addition, there is an evaluation of the limits of conventional design procedures, in so far as notch brittleness is concerned, and recommendations for the utilization of available notch-brittle test data.

A summary of five pages gives the engineer condensed information as to the choices which he may use in designing to prevent brittle failure in applications where notch toughness is recognized as being important.

At the end of the volume are included a Summary and a Glossary of Terms related to steel structures and research in notch brittleness. A list of suggested reading in the areas of (1) theory, (2) research and fabrication, materials, design and (3) service data is appended.

This volume was written to aid practicing designers and fabricators. The information set forth in this book was considered in the realistic light of economic considerations and structural requirements. Wherever possible, the authors have endeavored to indicate the economic advantages and penalties associated with various possible procedures and courses of action connected with avoidance of brittle failure in steel structures.

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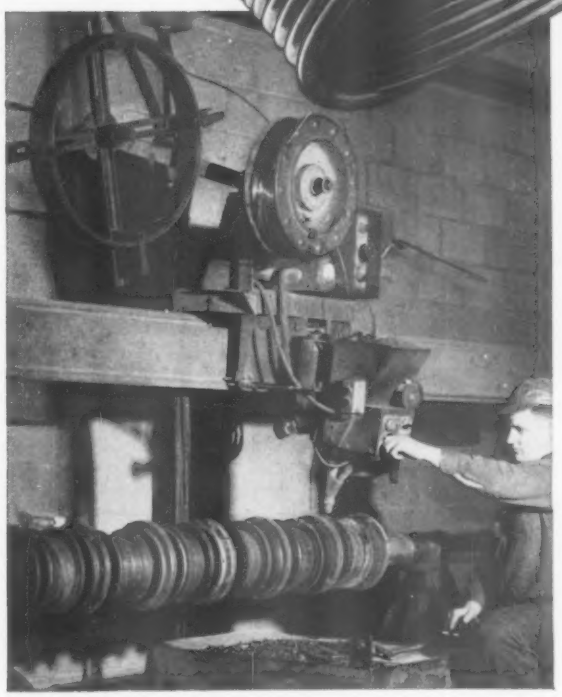

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NEW PRODUCTS

Spot Kit

Air Reduction has just announced the availability of an Aircomatic spot kit that converts standard Model 21 manual Aircomatic welding guns for arc spot welding.

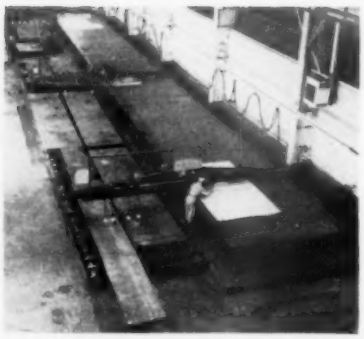
The kit consists of an auxiliary control panel, an outer barrel and a flat nozzle. Spot welding of lap joints, or tack welds in a butt, lap or fillet joint, can be made on mild and stainless steels.

Standard Model 21 guns are rated at 350 amp continuous duty, d-c reverse polarity for regular gas-shielded metal-arc welding. For arc spot welding only, due to the reduced duty cycle, the gun can be used up to 500 amp d-c reverse polarity.

Additional information can be obtained by writing Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Shape-Cutting Machine

The flame shape-cutting machine, pictured herewith, believed to be the longest ever built (124 ft), cuts heavy steel into welding parts for the largest overhead ladle cranes in the world. The unit was designed by National Cylinder Gas Co. and installed in the Alliance (Ohio) plant of the Morgan Engineering Co. Four electrically controlled oxyacetylene cutting torches are mounted on each of two of the cutting unit carriages (foreground) and six on the third. Using an oxyacetylene flame as the "knife," the



cutting machine carriages range from one end of a table to the other, cutting heavy steel into intricate shapes conforming to a pattern laid on the continuous-length tracing table. As many as six identical shapes can be cut at one time in heavy blocks of steel or stacks of steel plate as much as 2-ft thick or more.

For additional details, write to National Cylinder Gas Co., 840 N. Michigan Ave., Chicago 11, Ill.

Welders' Lenses

The Buell W. Nutt Co., 11614 W. Pico Blvd., Los Angeles 64, Calif., announces the availability of Seeweld plates. They are plastic plates in which optical lenses of different magnifying powers are inserted. These plates are placed in goggles or helmets and take the place of spectacles which may then be discarded.

A table is provided to enable welders themselves to make a selection of the proper Seeweld for their individual use.

A copy of the folder "Better Vision For Welders," containing complete information about the use of Seeweld Plates and the table for selection will be sent to all who are interested in getting this information.

Write directly to the manufacturer at the above address.

Aluminum Bronze Electrode

Utility of the metallic arc in production and maintenance operations is broadened by the availability of a general-purpose shielded-arc aluminum bronze electrode, according to an announcement by All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y.

The electrode can be used with D-C reverse or high-open-circuit A-C.

Designated Arc-Braze No. 20, it is recommended by manufacturer for use on bearings, axle stops, bushings, pump pistons, end bell housings, clutch yokes, rails, cylinder blocks, gear housings, foundry flasks, paper mill rolls, heater heads, impeller hubs, propellers, valve parts, motor housings, broaches, milling cutters, gear teeth and spindles.

Arc-Braze No. 20 is available in $^1/_8$, $^5/_{32}$ and $^3/_{16}$ in. diameters.

For additional details, write directly to All-State at the above address.

Hard Surfacing Electrodes

A new line of hard-surfacing electrodes with low-hydrogen coatings has been introduced by Metal & Thermit Corp., Rahway, N. J. Designated Hardex, the new line includes 14 different types of electrodes, each designed to combat a specific type of wear.

According to manufacturer, the new electrodes present a new approach to improved wear resistance and quality of hard surfacing. With less moisture in the coating, weld metal porosity is reduced and there is less cracking. Extensive field testing also reveals that penetration into the base metal and dilution by the base metal is at a minimum, and greater resistance to impact, abrasion and corrosion are obtained.

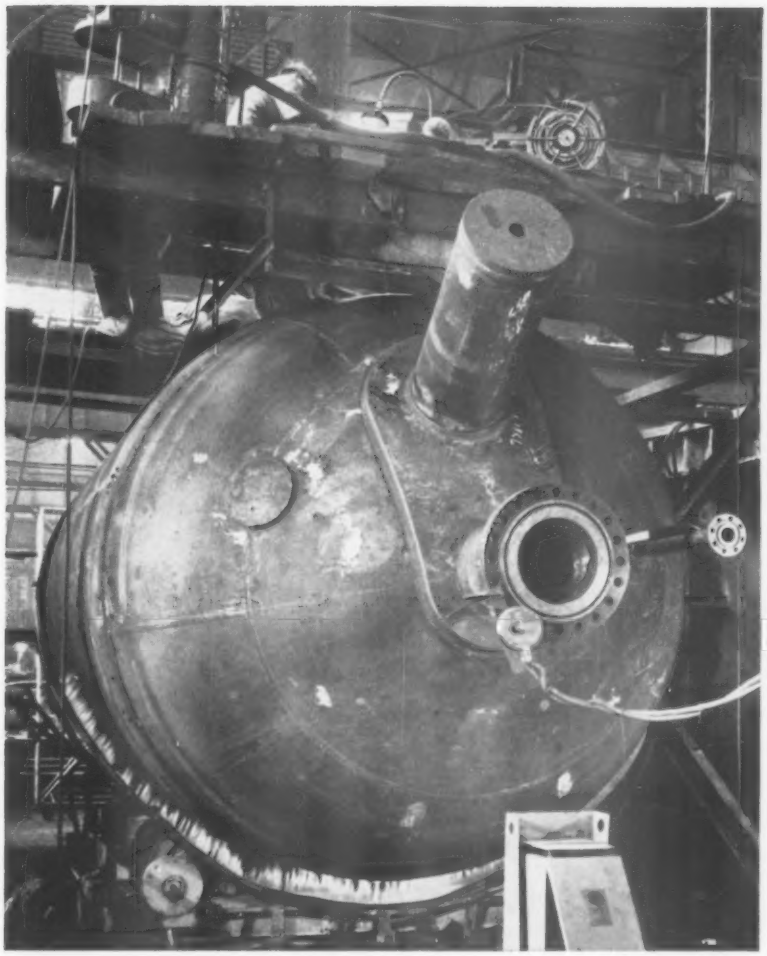
The electrodes may be used with either alternating or direct current employing ordinary welding techniques.

Literature is available upon request. Write to Metal & Thermit Corp., Rahway, N. J.

Nozzle Compound

Linde 65 Sigma Nozzle Compound, a new silicone-containing compound that eliminates costly work stoppages caused by splatter-encrusted welding nozzles, has been introduced by Linde Co., a Division of Union Carbide Corp. Applied to the nozzle before welding, 65 Compound forms a thin protective coating over the bore and mouth of the nozzle. This invisible coating prevents molten splatter from sticking to nozzle surfaces, thus eliminating the downtime normally required to clean nozzles before welding can continue.

Under normal operating conditions,



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Why not discuss your stainless welding wire needs with your *Drawalloy* Distributor or Representative . . . a man ready to help you. Bulletin 355-DC provides complete information on every grade of *Drawalloy* wire. Write to: Drawalloy Corporation, Lincoln Highway West at Alloy Street, York 13, Pennsylvania.

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a thin coating of 64 Compound will give nozzles full 8-hr protection. However, where the current level is high or unusual welding conditions exist, 65 Compound should be applied every 4 hr or less to assure continued nozzle protection.

Free copies of an illustrated folder describing new Linde 65 Compound may be obtained by writing to Linde Co., 30 E. 42nd St., New York 17, N. Y. and asking for Form 1049.

ML-2 Power Pack

The Lincoln Electric Co. has announced a new Power Pack attachment for their 500-amp combination AC and DC Idealarc welder which is designed to permit use of the welder as a power source for the Manual Lincolnweld, ML-2, semiautomatic submerged-arc welder.

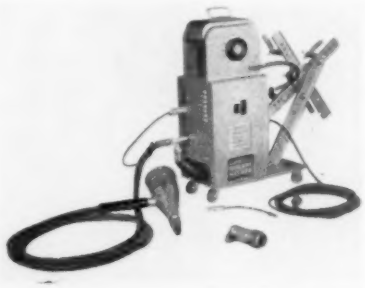
The combination of the Idealarc welder, the ML-2 submerged-arc welder and the Power Pack is intended to make a package capable of manual welding with d-c or a-c current and submerged-arc welding with d-c current.

The Idealarc operates on single-phase input power. Generator power sources for the ML-2 submerged-arc unit require three-phase current.

The Power Pack mounts directly on the Idealarc welder and is easily connected.

Semiautomatic Welding Unit

A new semiautomatic submerged-arc welding unit of compact and light-



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Note: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N.Y., no later than the 25th of the month previous to issue mailing.

weight design has just been announced by Hobart Bros. Co., Troy, Ohio.

The new unit is completely equipped with all controls and control power cable for plugging in on 110 v, either d-c or a-c wire reel, caster mounted base, and carrying handles. A gun cable assembly is included with two welding guns, which are interchangeable—one flux type with hopper and one open-arc type for welding without flux.

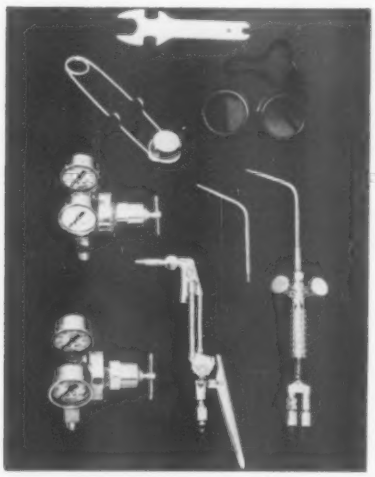
This unit is designed for use with any arc welder having continuous current up to 500 amp using solid wires $^{5}/_{64}$ or $^{3}/_{32}$ in., and tubular (fabricated) wires $^{3}/_{32}$ or $^{7}/_{64}$ in.—with either the flux type or open-arc type gun, depending on the job.

For more complete information, write to Hobart Brothers Co., Troy, Ohio.

Light-Duty Outfit

A new light-duty welding and cutting outfit has just been placed on the market by Air Reduction. Designed for performance in the light-to-medium range, it is especially suited for applications where intermittent service makes low cost a factor in equipment selection.

The outfit is designed to handle welding, brazing, heating and cutting operations. It will weld metals up to $^{3}/_{16}$ in. thick, or up to $^{5}/_{16}$ in. if larger



tips are used, and cut steel plate up to an inch thick.

All the equipment necessary to do a welding or cutting job is included in the light-duty outfit.

For complete information about the new light-duty welding and cutting outfit, refer to the local authorized Airco dealer or write Air Reduction Sales Co., a division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

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213	475	1400
225	488	1450
238	500	1500
250	550	1550
263	600	1600
275	650	1650
288	700	1700
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Welding Research

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W. SPRARAGEN, DIRECTOR

SUPPLEMENT TO THE WELDING JOURNAL, JUNE, 1957

TIME-TEMPERATURE EFFECT ON PROPERTIES OF WELD HEAT-AFFECTED ZONE IN TYPE 347 STAINLESS STEEL

Mechanical properties of Type 347 weld heat-affected zones are not impaired by high-temperature heat treatments. Corrosion resistance in nitric acid, however, is time-temperature dependent

BY E. F. NIPPES, B. SCHAAF, W. L. FLEISCHMANN AND R. L. MEHAN

ABSTRACT. To obtain an understanding of the metallurgical changes occurring in the weld heat-affected zone of Type 347 stainless steel during welding and subsequently in service, an investigation was conducted in the Metallurgical Department of Rensselaer Polytechnic Institute. The initial report covered the establishment of the heating and cooling cycles occurring in metal-arc welding of a $1^1/_2$-in. thick plate. Some data were presented which spotted the potentially troublesome area in the region heated to about 2400° F. The work which is presented in this paper concentrated on the behavior of samples heated in synthetic welding cycles to a peak temperature of 2450° F. The brief duration of that temperature was sufficient to cause concomitant grain growth and solution of the carbide phase. This condition simulated those existing in that region of actual welds where troubles were experienced. The general type of information which this work was intended to provide was to establish the time-temperature behavior of the high-temperature metallurgical structure (2450° F) established in the welding cycle.

E. F. Nippes is associated with Rensselaer Polytechnic Institute, Troy, N. Y., **B. Schaaf** is associated with Westinghouse Electric Corp., Philadelphia, Pa., **W. L. Fleischmann** and **R. L. Mehan** are associated with Knolls Atomic Power Laboratory, General Electric Co., Schenectady, N. Y. The Knolls Atomic Power Laboratory is operated by the General Electric Co. for the Atomic Energy Commission. The work here was carried out under Contract W-31-109 Eng. 52.

Presented at the 1956 AWS National Spring Meeting in Buffalo, N. Y., May 9–11.

Paper presented at the ASME Metals Engineering Division Conference held in conjunction with the 1956 AWS National Spring Meeting, May 7 to 11, Buffalo, N. Y.

Introduction

Among the stainless chromium-nickel steels, columbium-stabilized 18 chromium-8 nickel-1 columbium (Type 347) has become one of the most widely used in the power and nuclear reactor industries. Both industries require that equipment operate with utmost reliability and adverse experiences are usually the beginning of intensive investigations into the cause of difficulties.

Although, in general, Type 347 stainless steel has performed well, there have been reports of certain shortcomings which have been summarized by Poole.[1] In this survey about one half of the fabricators interviewed reported base-metal cracking in the weld heat-affected zone. This type of failure is insidious because it also has been observed after extended service. It was the purpose of this paper to examine in more detail the weld heat-affected zone in Type 347 stainless steel.

The following specific areas were studied in this investigation:

1. To establish the type of carbides which precipitate from the grain-coarsened supersaturated austenite of the weld heat-affected zone upon exposure to elevated temperatures.
2. To determine the changes in the metallurgical phases and the resultant mechanical and corrosion property changes as they might occur over long periods of time at elevated temperatures.
3. To indicate the importance of nickel content by comparing test results obtained from simulated test specimens of a high and a low-nickel Type 347 stainless steel, both within AISI specifications for this material.
4. To make a limited number of tests on simulated specimens of Type 304 stainless steel in order to establish a base line for the evaluation of the Type 347 data.

Procedure

Material

Type 347 stainless steel is considered an austenitic steel. Its composition range, however, is wide enough to allow the presence of small amounts of a ferritic phase. The fully austenitic Type 347 stainless steel is usually found in pierced products, like pipes and tubes, because the piercing operation demands a single-phase alloy for the avoidance of rupture. Hence, a minimum of 10% nickel is used in

Table 1—Percentage Composition of Steels Studied

Alloy designation	*High-Ni 347 A*	*Low-Ni 347 D*	*Low-Ni 347 E*
C	0.074	0.078	0.074
Mn	1.80	1.58	1.49
Si	0.48	0.55	0.65
Cr	18.21	17.61	18.07
Ni	12.75	9.75	9.59
Mo	0.15	0.31	0.21
S	0.029	0.014	0.030
P	0.019	0.018	0.020
Cu	0.24	0.29	0.20
Co	...	...	0.25
Cb	0.93 Cb + Ta	0.87	0.78
Ta	0.05	...	0.08
N	0.029	0.027	0.038
Cb/C	12.6	10.4*	10.5
Cb + Ta / C	12.9	10.8	11.1

* Estimated since only Cb + Ta is known.

pierced tubular products. A duplex alloy, however, can be tolerated in hot rolling and less than 10% nickel can be found in sheet, plate and bar.

To determine possible differences in the behavior of weld heat-affected zones in high- and low-nickel Type 347 stainless steel, three different compositions were tested. These compositions are shown in Table 1. The high-nickel alloy is designated in Table 1 as alloy "A" and the two lower-nickel alloys as "D" and "E." The material used was hot-rolled and annealed bar, $^{11}/_{16}$-in. diam.

Preparation of Test Samples

The synthetic weld heat-affected zone was produced on the RPI time-temperature controller which has been discussed in the literature.[2] The time-temperature cycle used here for the production of the 2450° F region of the weld heat-affected zone was the same as used in the preceding investigation. Figure 1, taken from that paper, shows this time-temperature relationship.

The selection of the 2450° F temperature was a compromise between reproducibility and peak temperature. Though samples representing the 2500° F peak-temperature region would perhaps show more striking results, reproducibility of samples at that high temperature was difficult to obtain because the temperature control did not respond fast enough to control the heat input within 1 cycle per sec. One additional pulse caused incipient melting and so ruined the sample.

The dimensions of the specimens treated with the time-temperature controller were as follows: (1) 0.4 in. square, 2.5 in. length for impact testing, (2) 0.50 in. diam, 3 in. length for stress-rupture, corrosion, tensile and metallographic study.

A chromel-alumel couple was percussion-welded to each specimen, halfway from the ends into a 0.052-in. diam hole approximately 0.05 in. deep. In the production of the synthetic weld heat-affected zone, the output of this thermocouple was balanced against the signal controlled by the selected cam. Thus the heating and cooling rates simulating the welded thermal cycle were reproduced on the modified flash welder in whose water-cooled copper jaws the specimen was clamped. The maximum distance between the jaws which still gave a uniform microstructure along the critical test section of the specimens and also simulated the cooling rates was found to be 0.6 in. Under these optimum conditions, the uniform microstructure existed for about 0.3 in. in samples exposed to the high peak temperature. The accuracy of the temperature measurement can be assumed to be ± 25° F which, at the high heating rates, is considered to be the best obtainable.

Heat Treatments

The simulated weld heat-affected-zone test samples were subjected to a variety of sensitizing treatments to detect any metallurgical phase changes and resultant mechanical and corrosion property changes. The sensitizing treatments with their corresponding parameter values† are listed in Table 2. Table 3 shows the types of tests that these specimens were subjected to. In addition to these samples, as-received material was also subjected to the tests in Table 3.

† The effects of the sensitizing treatments are a function of the temperature and the time at temperature. These variables may be expressed as a single term by means of the general time-temperature parameter, $M = T (20 + \log t) \times 10^{-3}$, where T is expressed in deg R and t in hours.[3]

Table 2—Sensitizing Treatments After Synthetic Weld Heat-Affected Zone Treatment (2450°F)

Specimen designation	*Temperature, °F*	*Time, hr*	*Parameter[3]**
H	1000	40	31.5
J	1000	400	33.0
T	1200	1	33.2
K	1150	10	33.8
U	1300	1	35.2
L	1150	100	35.4
M	1150	1000	37.0
N	1300	10	37.0
P	1300	100	38.7
R	1300	1000	40.5
XL	As-Received + 1900°F − 2 hr + 1150° F − 100 hr		35.4
YP	As-Received + 1300° F − 100 hr		38.7

* M = T (20 + log T) where: T = Temperature, °R.
t = time, hr.

Each of the temperatures of the sensitizing treatment were maintained with a maximum of ±12° F variation. In order to keep the brief heating times within accurate limits, a lead pot was used for the 1 hr treatments. A forced-circulation air furnace was used for treatments of 10, 100 and 1000 hr, inclusive. Dummy specimens with thermocouples in their geometric centers were used to insure uniform furnace temperatures and to establish the time lag required for the given temperature to be reached.

Test Specimens

Tensile test specimens were machined from round synthetically welded specimens. The specimens were 0.250 in. diam with a 1.0 in. gage length. They were machined so the peak thermal cycle band was in the center of the gage length. Impact specimens were standard Charpy V-notch specimens machined from square synthetically welded samples. The peak thermal cycle band was at the center of the specimen.

Stress-rupture specimens were 0.357 in. diam with a 1.06 in. gage length. The specimen had a 60° notch 0.052

Table 3—Summary of Tests Performed on Synthetically-Welded Stainless-Steel Specimens

Material	*Tensile test*	*Impact test*	*Stress-rupture test*	*Boiling HNO_3 test*	*Metallographic examination*	*Strauss test*	*X-ray diffraction studies*
High-Ni 347 (A)	X	X	X	X	X	X	X
Low-Ni 347 (D)	X	X	–	X	X	X	X
Low-Ni 347 (E)	X	X	–	X	X	X	X
304 Stainless Steel	–	X	–	X	–	–	–

X = Tests Performed.
– = Tests Not Performed.

Table 4—X-ray Phase Identification Date—Sensitizing Treatments

	1000° F		1150° F			1300° F			*As-received, 1300°*
	40 hr	*400 hr*	*10 hr*	*100 hr*	*1000 hr*	*10 hr*	*100 hr*	*1000 hr*	*100 hr*
High-Ni 347 "A"	CbC (H)	CbC (H) $Cr_{23}C_6$ (H) Sigma (L)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (H) Sigma (L)	CbC (H) $Cr_{23}C_6$ (M)	CbC (H) $Cr_{23}C_6$ (L) Sigma (L)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (M)
Low-Ni 347 "D"	CbC (H) $Cr_{23}C_6$ (L)	CbC (H) $Cr_{23}C_6$ (M) Sigma (M)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (L)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (L)
Low-Ni 347 "E"	CbC (H) $Cr_{23}C_6$ (L)	CbC (H) $Cr_{23}C_6$ (M) Sigma (L)	CbC (H) $Cr_{23}C_6$ (H) Sigma (M)	CbC (H) $Cr_{23}C_6$ (H) Sigma (M)	CbC (H) $Cr_{23}C_6$ (H) Sigma (M)	CbC (H) $Cr_{23}C_6$ (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (M)	CbC (H) $Cr_{23}C_6$ (M) Sigma (H)	CbC (H) $Cr_{23}C_6$ (M) Sigma (H)

H—11–15 lines on pattern. M—6–10 lines on pattern. L—0–5 lines on pattern.

NOTE: The CbC lines were always the highest intensity lines on the pattern and there were always eleven CbC lines on each pattern.

in. deep with a 0.005 in. radius at the base. The peak thermal-cycle band was at the base of the notch.

The samples used for the metallographic study and the boiling 65 percent HNO_3 corrosion test were thin disks 0.385 in. diam and 0.10 in. thick machined from the center of the 0.50 in. diam synthetically-welded specimens. The disks were thus composed entirely of material which had been subjected to the peak thermal-cycle temperature of 2450° F. The Strauss specimens were 0.125- x 0.375- x 3-in. samples machined from the 0.50 in. diam synthetically - welded specimens. The specimens were machined in such a way that only a band of approximately 0.25 in. through the center of the flat test specimen had experienced the peak thermal cycle.

Test Results

Metallographic Structure

The as-received material was fine-grained with the carbide phase well dispersed in dot form except for a limited number of larger inclusions. Considerable grain growth was produced in the material by the synthetic weld heat treatment of 2450° F. The dot carbides originally present completely disappeared as a result of this treatment. The larger inclusions appeared undisturbed.

Sensitization treatments at lower temperatures and shorter times produced a fine continuous precipitate at the grain boundaries. Higher temperatures and longer times caused this precipitate to agglomerate and lose its continuity along the grain boundaries.

Photomicrographs showing the as-received, as-welded, and sensitized structures for the high-nickel 347 steel are shown in Fig. 2. The behavior is the same with the other 347 steels investigated.

Phase changes produced in the grain-coarsened, supersaturated austenite of the weld heat-affected zone due to exposure to the various sensitizing treatments were studied by X-ray diffraction. Carbides and sigma phase were concentrated by subjecting the samples to Villela's reagent which preferentially dissolved the matrix. Patterns were produced by subjecting the concentrate to nickel-filtered copper radiation in a 4.5 in. diam Straumanis (internal calibration) type Debye-Scherrer camera. In addition to CbC and/or CbN, which was found in all samples, $Cr_{23}C_6$ and/or the Fe-Cr sigma phases were produced in all of the sensitization treatments.

Although it was not possible to obtain a quantitative analysis from the X-ray powder patterns visual comparison of patterns indicated a greater amount of precipitate after the sensitizing treatments at higher temperatures and for longer times. This seems particularly true for the sigma phase, since the highest temperature and longest time treatment (1300° F for 1000 hr) produced the greatest amount of this phase as indicated by the number and strength of the lines on the pattern. This was true of all the alloys investigated (Table 3).

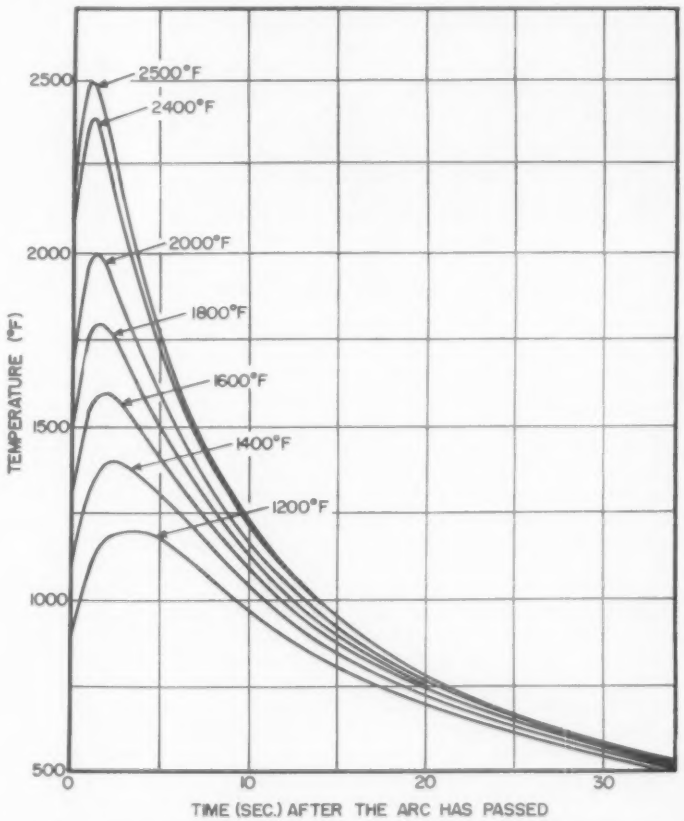
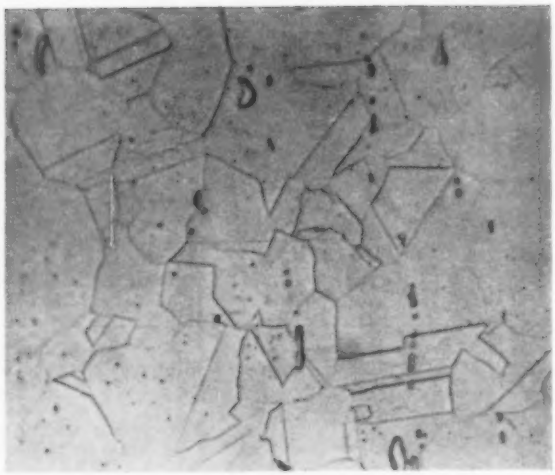
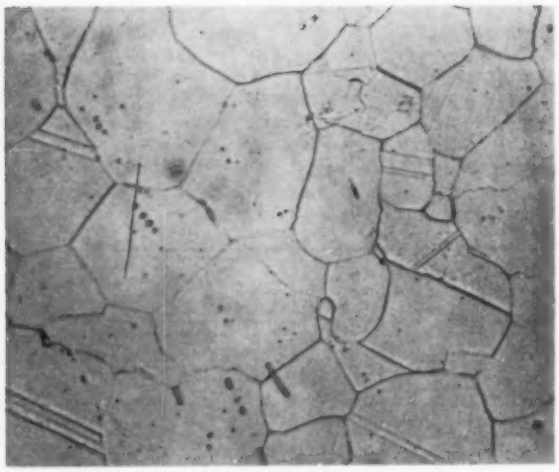


Fig. 1 Time-temperature cycles adjacent to arc welds in $1\frac{1}{2}$-in. Type 347 stainless-steel plate, peak temperatures as indicated, 30,000 joules/in. Energy input; no preheat

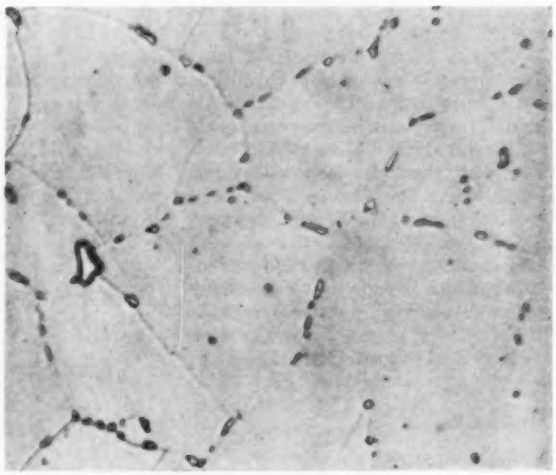
A. As received



B. As synthetically welded



C. Synthetically welded + 1000° F—400 hours



D. Synthetically welded + 1300° F—1000 hours

Fig. 2 Photomicrographs of high-nickel steel in various sensitized conditions. Etchant: Mixed acids. X 750

Patterns produced from the "as-received" and synthetically heat-treated specimens showed the presence of the CbC phase in all cases. $Cr_{23}C_6$ was present only in the two low-Ni, synthetically heat-treated specimens. Table 4 gives the results of the X-ray diffraction studies on the three 347 stainless steels.

Corrosion Properties

The disk-type corrosion specimens (0.375 in. diam and 0.10 in. thick) were subjected to attack by boiling 65 percent nitric acid. Each specimen was exposed to the acid for five 48-hr periods. Fresh solutions were used for each period. The weight loss due to corrosion was converted to inches per month penetration in accordance with the ASTM standard conversion. This calculated corrosion rate is shown in Fig. 2 as a function of the sensitizing parameter.

The weld heat-affected zone in the as-welded condition was not attacked by the boiling nitric acid. This is in agreement with the previous report in this investigation where it was shown that the corrosion rate is independent of the peak heat-treating temperature.[1]

After sensitization in the carbide-precipitation range (800–1500° F) the corrosion rate first increases rapidly with increasing parameter, and then decreases. The rapid corrosion rate is associated with those structures showing a continuous carbide network at the grain boundaries and the slower rates with agglomerated carbides (Fig. 3).

In general, the high-nickel-content Type 347 stainless steel seems more susceptible to this attack than the lower-nickel-content specimens. A group of Type 304 stainless-steel specimens prepared in an identical manner and subjected to boiling nitric exhibited a much higher corrosion rate than any of the Type 347 specimens.

Additional corrosion tests were conducted on the Type 347 alloys in an acidified boiling copper-sulphate solution (Strauss test). The following composition was chosen:

13g $CuSO_4 \cdot 5H_2O$
47 ml H_2SO_4 (96%)
Distilled water to make 1 liter

It has been reported that a resistance increase of 1.0 percent is indicative of intergranular attack. After four 72-hr periods of exposure, the greatest increase in resistance noted on these Type 347 specimens was less than one half of this value. Hence it seems that intergranular attack does not occur after 288 hr of exposure to this medium.

Mechanical Properties

The effect of welding and subsequent

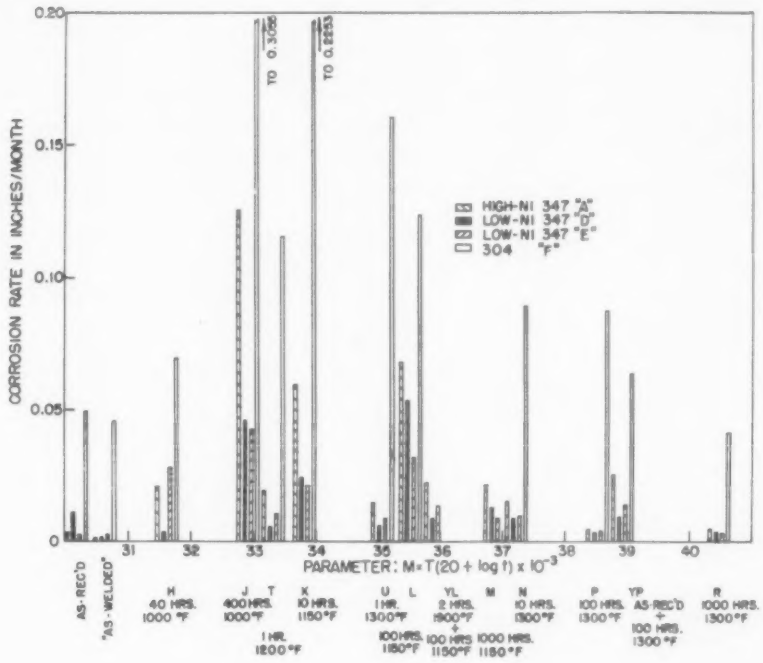


Fig. 3 Boiling 65% nitric acid corrosion-test results for stainless steel in various sensitized conditions

sensitization treatments on the mechanical properties of the weld heat-affected zone is presented in Table 5. The room-temperature tensile and yield strength of the as-welded specimens decreased slightly from the as-received values. The percent elongation decreased considerably as a result of the post-weld heat treatment. Reduction in area was not affected as a result of welding but sensitization at high temperatures and long times caused a slight decrease.

The elevated (1200° F) temperature tensile tests did not reveal any appreciable effects on the tensile strength, elongation, or reduction in area. Yield-strength data were erratic and no trend is evident.

The impact-test results show no appreciable change as a result of welding. There is a general trend toward lower impact strengths with increasing parameter.

Notched-bar stress-rupture tests were conducted only on the high-nickel Type 347. Results of these tests are shown in Fig. 4. Examination of the data shows the as-welded and double-heat-treated specimens closely approximate the values obtained on as-received specimens.

Table 5—Mechanical-Test Results for Stainless Steels in Various Sensitized Conditions

			Room Temperature Tensile Data				1200° F Tensile Data				Charpy V-notch impact strength at RT
Material	Heat treatment	Parameter	Tensile strength psi	0.2% Yield strength psi	Elongation in 2 in. %	Reduction in area %	Tensile strength psi	0.2% Yield strength psi	Elongation in 2 in. %	Reduction in area %	ft-lb
High-Ni 347	As received	..	92,900	46,100	56.2	70.7	51,700	31,200	40.5	61.9	145
"	As welded	..	85,200	41,300	40.3	72.7	53,600	27,000	34.0	64.6	143
"	As welded + 1000° F for 40 hr	31.5	88,800	45,700	40.1	71.3	53,500	28,500	32.1	66.0	182
"	As welded + 1000° F for 400 hr	33.0	83,800	39,000	42.2	70.0	54,500	26,800	33.3	67.2	121
"	As welded + 1150° F for 10 hr	33.8	88,400	46,500	40.6	72.0	54,100	30,400	30.7	65.3	152
"	As welded + 1150° F for 100 hr	35.4	89,300	47,000	39.0	69.8	54,000	29,700	30.0	60.7	128
"	As welded + 1150° F for 1000 hr	37.0	90,300	49,800	34.4	65.0	53,700	30,300	32.3	63.2	81
"	As welded + 1300° F for 10 hr	37.0	89,000	45,400	39.5	71.7	52,100	34,800	32.8	68.7	124
"	As welded + 1300° F 100 hr	38.7	91,000	45,600	39.5	67.1	51,100	29,900	24.7	67.3	107
"	As welded + 1300° F for 1000 hr	40.5	87,400	38,900	36.7	64.5	48,400	25,800	27.6	64.3	65
"	As welded + 1900° F for 2 hr + 1150° F for 100 hr	..	88,200	37,900	42.7	66.6	51,800	25,000	29.2	68.3	103
"	As received + 1300° F for 100 hr	..	92,700	48,600	50.0	69.0	53,400	30,700	43.2	67.9	123
Low-Ni 347	As received	..	95,900	44,500	61.4	75.5	53,600	25,100	37.5	67.4	161
"	As welded	..	88,000	43,500	44.3	76.0	53,100	23,000	34.4	70.7	138
"	As welded + 1000° F for 40 hr	31.5	90,200	45,300	43.8	74.7	52,600	23,000	32.0	70.0	181
"	As welded + 1000° F for 400 hr	33.0	90,700	45,200	42.2	76.0	55,500	26,500	32.8	68.7	154
"	As welded + 1150° F for 10 hr	33.8	90,400	43,800	46.4	76.7	54,100	24,000	31.8	69.3	172
"	As welded + 1150° F for 100 hr	35.4	92,400	48,600	42.7	73.3	53,000	25,500	30.7	66.6	145
"	As welded + 1150° F for 1000 hr	37.0	92,600	47,300	39.6	70.0	52,200	29,800	29.7	66.0	97
"	As welded + 1300° F for 10 hr	37.0	92,000	46,200	45.3	72.7	54,400	25,000	31.2	69.0	143
"	As welded + 1300° F for 100 hr	38.7	90,700	48,500	44.3	74.0	50,100	28,900	30.2	68.7	128
"	As welded + 1300° F for 1000 hr	40.5	91,500	40,300	41.1	69.7	48,300	25,500	28.7	69.8	70
"	As welded + 1900° F for 2 hr + 1150° F for 100 hr	..	93,500	40,700	47.4	73.3	52,000	23,800	30.8	70.0	142
"	As received + 1300° F for 100 hr	..	96,600	52,000	53.9	74.0	53,200	26,100	36.5	68.2	135
"	As received	..	100,100	48,100	57.8	71.4	54,100	31,800	38.4	66.0	118
"	As welded	..	93,300	49,400	49.0	73.3	54,900	27,500	31.8	66.0	140
"	As welded + 1000° F for 40 hr	31.5	96,000	51,500	51.0	74.0	53,500	29,500	31.8	60.0	153
"	As welded + 1000° F for 400 hr	33.0	96,100	55,600	44.8	69.3	56,800	30,600	33.9	65.7	122
"	As welded + 1150° F for 10 hr	33.8	95,700	49,800	50.0	71.3	54,100	28,000	30.5	67.0	126
"	As welded + 1150° F for 100 hr	35.4	96,100	56,100	45.8	71.3	55,100	30,500	32.8	64.0	123
"	As welded + 1150° F for 1000 hr	37.0	97,900	55,100	44.3	68.7	54,500	39,500	32.3	62.7	83
"	As welded + 1300° F for 10 hr	37.0	96,100	52,100	49.0	72.0	54,000	30,300	34.9	66.7	136
"	As welded + 1300° F for 100 hr	38.7	95,800	50,300	44.3	68.6	51,700	33,500	29.7	64.7	92
"	As welded + 1300° F for 1000 hr	40.5	96,900	45,700	35.4	58.5	50,500	26,400	27.6	62.4	39
"	As welded + 1900° F for 2 hr + 1150° F for 100 hr	..	99,200	52,200	52.1	68.6	54,500	34,100	41.7	67.3	142
"	As received + 1300° F for 100 hr	..	93,700	40,200	52.1	73.3	53,700	25,000	33.6	59.0	135
304	As received	..	No tests performed				No tests performed				148
"	As welded	..	"				"				207
"	As welded + 1000° F for 40 hr	31.5	"				"				217
"	As welded + 1000° F for 400 hr	33.0	"				"				213
"	As welded + 1150° F for 10 hr	33.8	"				"				200
"	As welded + 1150° F for 100 hr	35.4	"				"				..
"	As welded + 1150° F for 1000 hr	37.0	"				"				..
"	As welded + 1300° F for 10 hr	37.0	"				"				153
"	As welded + 1300° F for 100 hr	38.7	"				"				132
"	As welded + 1300° F for 1000 hr	40.5	"				"				100
"	As welded + 1900° F for 2 hr + 1150° F for 100 hr	..	"				"				128
"	As received + 1300° F for 100 hr	..	"				"				110

Discussion

The purpose of this investigation was to determine whether welding *per se* had any deleterious effects on the service behavior of weld heat-affected zones of Type 347 stainless steel.

The immediate effect of welding on base-metal ductility of Type 347 was recently reported by RPI.[4] Another series of tests which could perhaps be called general weldability tests for austenitic stainless steels was discussed by Pellini and Puzak.[5] They found that liquation of a low melting point phase could explain failure during welding, stress-relief treatments, and later in service.

The tests reported here were conducted on samples in which liquation was avoided in favor of consistency among samples. Hence the data discussed cover sections of the weld heat-affected zone adjacent to the region reported as the trouble spot by Pellini and Puzak.

The results which are discussed in the following paragraphs are based on samples which represent the 2450° F temperature region of the weld heat-affected zone. To simulate time at temperature all samples except those of the rupture series cover time-temperature periods from 40 hr at 1000° F to 1000 hr at 1300° F. The latter figure is considered to be equivalent to more than 100,000 hr at 1000° F.

The tensile-test results (room temperature and 1200° F) do not show any effect that can be considered of any consequence. The impact tests at room temperature show a drop from a high value (about 160 ft-lb) to approximately 60 ft-lb over the sensitization range (parameter of 31.5 to 40.5). The meaning of this loss in energy absorption is difficult to evaluate in terms of service behavior.

Rupture tests were conducted to explore more fully the apparent loss in rupture ductility reported in the first paper.[2] Because a loss in rupture ductility might be interpreted as a lack of notch ductility, a series of notched-bar rupture tests were conducted at 1200° F. The heat-treating cycles to which the samples were exposed after the synthetic welding cycle are considered equivalent to those now employed in the power industry.[6] The present results indicate that weld heat-affected zones of Type 347 do not exhibit notch sensitivity because the slope of the as-welded rupture curve (Fig. 4) is less than that of the as-received specimens.

X-ray diffraction results show that, in addition to the CbC and/or CbN found in all samples, sensitization heat-treatments produce $Cr_{23}C_6$ and the iron-chromium sigma phase. There does not seem to be close correlation between the amounts of $Cr_{23}C_6$ as reported in Table 4 and the corrosion data shown in Fig. 3. This is probably due in part

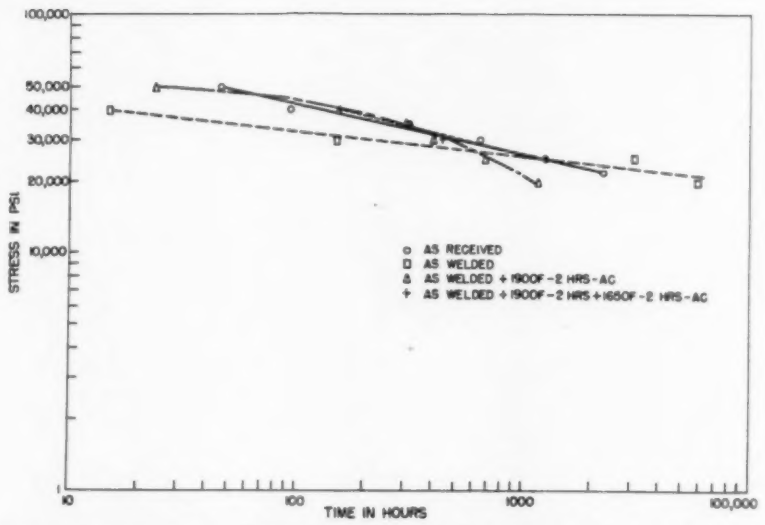


Fig. 4 Stress-rupture strength of high-nickel 347 stainless steel in various heat-treated conditions

to the qualitative nature of determining the amounts of the phases present. In addition, only a small proportion of the CbC and/or CbN is dissolved during the weld thermal cycle; hence the large amount of remaining material tends to mask the comparatively small amount of precipitate formed during subsequent sensitizing treatments.

Corrosion tests conducted on wafer-type specimens do indicate a definite correlation between sensitizing treatments and corrosion rates. Figure 3 shows that the corrosion rate initially increases with increasing times and temperatures, and then decreases.

The explanation for this behavior lies with the nature of the carbide phase. The peak welding temperature of 2450° F is sufficient to dissolve the columbium carbides, making available free carbon in the austenitic phase. When such a specimen is heated in the sensitization range, the carbon precipitates as chromium carbide ($Cr_{23}C_6$) at the grain boundaries This condition leads to intergranular corrosion because of depletion of chromium in the vicinity of the grain boundaries.[7] Figure 2 (*c*) shows a structure typical of a specimen which showed a high corrosion rate. The grain boundaries are heavily delineated by a network of chromium carbide.

Increasing the sensitizing time and temperature leads to agglomeration of the chromium carbide phase. According to the "chromium depletion" theory, free chromium has sufficient time to diffuse into the depleted regions at the grain boundaries.[7] A decrease in corrosion rate is noted. Figure 2 (*d*) shows the structure of a specimen with the agglomerated carbide phase at the grain boundaries.

The corrosion data in Fig. 3 also indicate that, for the particular heats studied, a high-nickel 347 stainless steel is more susceptible to intergranular corrosion than a low-nickel steel. It is possible that the presence of ferrite in the low-nickel steels provides precipitation sites for chromium carbides and reduces the severity of the grain-boundary effect.

The corrosion rates of the 304 stainless steel included for comparison are much higher in all the conditions investigated. This behavior would be anticipated for an unstabilized stainless steel subjected to sensitizing treatments.

Conclusions

For the heats of Type 347 stainless steel used and the heat-treatment employed, the following conclusions are reached:

1. High-temperature heat-treatments of Type 347 weld heat-affected zones do not impair the mechanical properties of this region. This does not preclude the possibility of liquation causing damage to the structure.

2. Corrosion in 65% boiling nitric acid of weld heat-affected zones is time-temperature dependent.

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FATIGUE RESISTANCE OF SIMULATED NOZZLES IN MODEL PRESSURE VESSELS

Report of PVRC-sponsored investigation describes mode of failure in critical areas under fatigue loading close to yield point pressure

BY GEORGES WELTER AND JULIEN DUBUC

SYNOPSIS. This paper brings together all observations concerning the fatigue resistance of simulated nozzles made during fatigue tests on model pressure vessels of A201, Grade A, and A302, Grade B steels under cyclic internal pressure. It was observed that all fatigue fractures in these nozzles occurred in the longitudinal direction of the pressure vessels and began at points of maximum circumferential stress concentration at the edge where the nozzle hole meets with the internal surface of the pressure vessel shell.

Introduction

This paper can be considered as a part of the previous report entitled "Investigation of Static and Fatigue Resistance of Model Pressure Vessels," published in July 1956 *Welding Research Supplement*. Its purpose is to describe more fully the behavior under fatigue stresses of the simulated nozzles welded to these pressure vessels.

Simulated Nozzles on Model Pressure Vessels

The dimensions of the model pressure vessel shells and method of installation of the nozzles are given in Fig. 2 of the previous report mentioned above, together with details of fabrication procedure. The nozzle design was chosen in order to create a high stress concentration to test the fatigue resistance of the shell material. The purpose was not to test the fatigue resistance of a particular type of design for nozzles.

These vessels were constructed in accordance with ASME Code for Unfired Pressure Vessels, 1949 Edition, paragraph U-68. The shells were press formed, at temperatures ranging from 1450 to 1800° F, in halves which were joined by two longitudinal weld seams. For welding of vessels of A201, Grade A steel, no preheat was used while vessels of A302, Grade B steel were welded with a preheat of 300 to 700° F; all the shells were stress-relieved at 1150° F.

The nozzles were made from a 2-in. diam bar welded to the shell and then bored to a $1^1/_4$ in. diam; the external end of the hole was plugged up by depositing weld material. This method of fabrication leaves the original shell material in place.

The boring of the $1^1/_4$-in. hole leaves

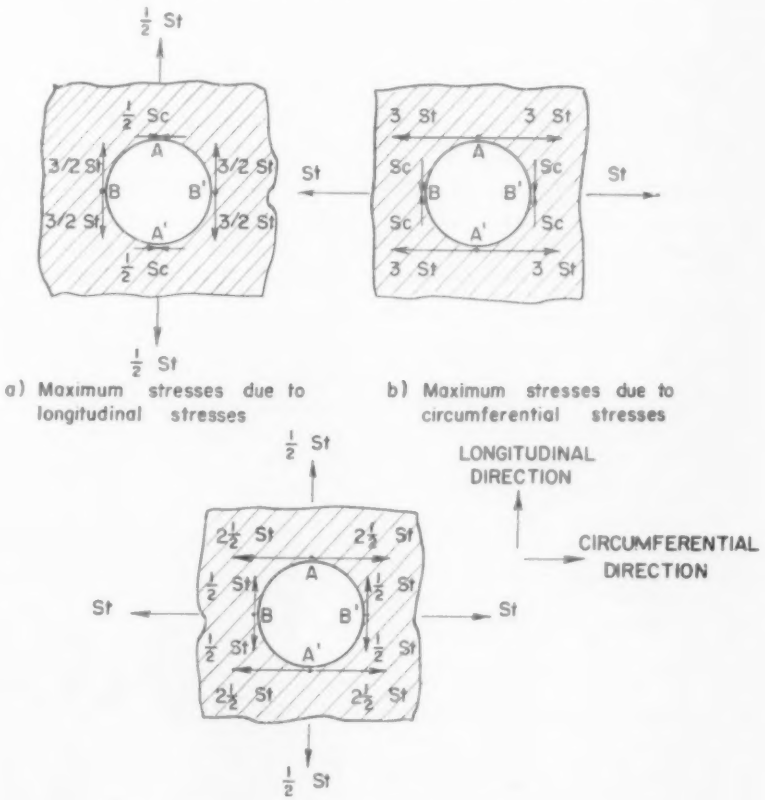

Fig. 1 Stress concentrations around a circular hole in a biaxial field of elastic stresses

Note: In a pressure vessel shell, the longitudinal tensile stress is $^1/_2$ the circumferential tensile stress S_t = tensile stress and S_c = compressive stress. This figure shows an idealized state of stress; the value of stress concentration factor should not be taken as that present in actual nozzles stressed above yield point.

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This investigation was carried out at École Polytechnique under the sponsorship of the Fabrication Division, Pressure Vessel Research Committee.

Presented at 1957 AWS National Spring Meeting in Philadelphia, Pa., April 8–12.

Table 1—Fatigue Resistance of Simulated Nozzles on Model Pressure Vessels

Vessel	Maximum cyclic pressure psi	Nozzle no.	Type of edge	No. of cycles applied	Remarks
"G" (A201, Grade A steel)	3675 (5% above yield pressure)	G-1	Square	50,960	Failure
		G-2	Square	51,267	Failure
		G-3	Square	51,267	Partial crack: nozzle cut out
		G-4	Square	51,267	Partial crack: nozzle cut out
"H" (A201, Grade A steel)	3300 (5% below yield pressure)	H-1	Square	87,547	Failure
		H-2	Square	102,972	Failure
		H-3	1/8 in. R	270,743	No failure: this result probably not significant, see discussion. Test stopped.
		H-4	1/8 in. R	270,743	
"L" (A302, Grade B steel)	6800 (13% above yield pressure)	L-1	Square	9,989	Failure
		L-2	Square	10,864	Failure
		L-3	Square	10,864	Partial crack: nozzle cut out
		L-4	Square	10,864	Partial crack: nozzle cut out
"M" (A302, Grade B steel)	5700 (5% below yield pressure)	M-1	Square	18,750	Failure
		M-2	Square	18,750	Partial crack: nozzle cut out
		M-3	1/8 in. R	36,138	No failure: This result probably not significant, see discussion. Test stopped.
		M-4	1/8 in. R	36,138	
"P" (A302, Grade B steel)	4950 (17.5% below yield pressure)	P-1	1/8 in. R	46,910	Failure
		P-2	1/8 in. R	53,518	Failure
"S" (A302, Grade B steel)	5000 (16.7% below yield pressure)	S-1	1/8 in. R	49,052	Failure
		S-2	1/8 in. R	49,052	Partial crack: nozzle cut out

a square edge where this hole meets the internal surface of the shell; nozzles so tested were said to have a "square edge." Other nozzles had this edge ground to a 1/8-in. radius; care was taken to have the striations parallel to the plane of stresses, that is, grinding was done in a circumferential direction when taking the axis of the nozzle as reference.

When a first set of nozzles had failed, they were taken off the vessel by cutting the shell around the nozzle along a 6-in. diam circle, approximately.

If a second set of nozzles were to be installed to continue fatigue tests, they were fabricated as described above, welded to a 6 in. diam (approx.) patch cut out of another shell of same material and stress relieved. The assembly was then welded to the shell, first from the inside and then from the outside; the weld was ground flush on both sides.

When a second set of nozzles was not desired, the hole was closed by welding in a patch taken from another shell of the same material. Some patches were welded from the outside of the shell only, using a backing bar, while some were welded from both sides; all welds were always ground flush. However, the backing bars could not, of course, be removed after welding.

Method of Testing

Static tests, as reported in our previous paper cited above, have shown that the shell of an A201, Grade A steel vessel began to yield at an internal pressure of 3500 psi while that of an A302, Grade B steel vessel began to yield at an internal pressure of 6000 psi; these values are called the yield pressure.

The pressure vessels, thus the nozzles, were tested in fatigue by applying, with suitable hydraulic pumps and controls, an internal pressure which was increased to a maximum value and then released to be reapplied cyclically until a fatigue crack was produced and the test stopped.

The nozzles were stressed by the biaxial stress field produced in the shell of the pressure vessels by the application of an internal pressure.

Figure 1 shows the theoretical stress concentration factors in the elastic range caused by a circular hole in a plate at points A, A′, B and B′. Figure 1*c* shows the total factors for the combined effect of the biaxial stress field existing in the shell of a pressure vessel, taking into consideration that the longitudinal stresses are 0.5 of the circumferential stresses. If the stresses are nowhere above the elastic range of the material, they are 2.5 times greater at points A and A′ than the circumferential membrane stresses; since, in all tests reported here, the vessels were stressed in the vicinity of their yield value, either below or above, it follows that, in the regions of stress concentration surrounding points A and A′, stresses were far above the yield value.

Under these conditions of stresses in the elasto-plastic range of the metals, the stress concentration factors given in Fig. 1 do not apply numerically, but still this analysis shows the location of the maximum stresses and that they must be rather high. It should be stated here that all failures at nozzles, without exception, occurred by a fatigue crack beginning at points A and A′ of the nozzles. These fatigue cracks then propagated through the wall to the outside surface of the shell; oil leakage through such a crack was taken as evidence of failure of a nozzle and the number of cycles at this point was recorded. Figure 5 shows the manner in which these fatigue cracks propagated through the wall.

Results

The complete testing history of all

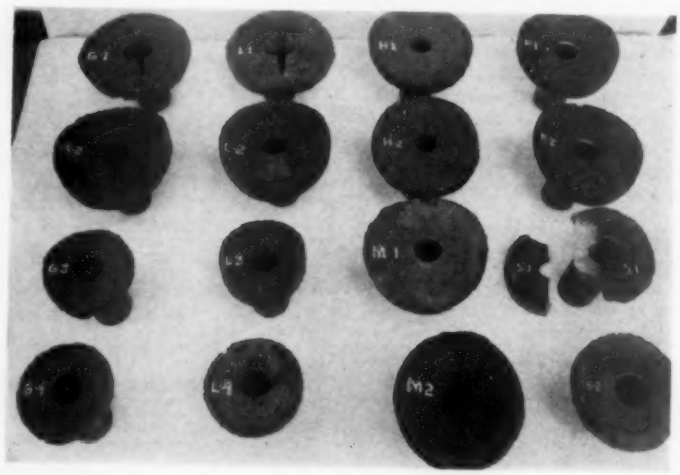


Fig. 2 View at internal surface of shell of all cut out nozzles

vessels, except vessel "S," can be found in our published paper referred to previously. Altogether, two vessels of A201, Grade A steel, designated "G" and "H" and four vessels of A302, Grade B steel, designated "L," "M," "P," and "S" were fatigue tested under constant maximum cyclic internal pressure.

Table 1 of this report gives all the data concerning the fatigue resistance of simulated nozzles on all model pressure vessels tested.

Figure 2 shows together all nozzles (view at internal surface of shell) which were cut out after testing. Figures 3*a–d* inclusive, reproduce typical drawings showing the location, direction and length of fatigue cracks at nozzles as seen at the internal surface of shell after nozzles had been cut out.

Some comments on each test now follow.

Vessel "G" of A201, Grade A Steel:

Nozzles G-1 and G-2 underwent failure as defined above. Figure 4*a* shows the longitudinal cracks in nozzle G-2. At this point nozzles G-3 and G-4 were removed and were found to have partial cracks, that is, these cracks had not yet traveled through the whole thickness of the wall.

After the nozzles had failed, they were cut out and replaced by welding in 6-in. diam patches, using two half-circle backing bars, covered by 10 to 12-in. diam cover plates welded on top. Some subsequent failures occurred through the welds of these patches, the crack originating apparently under one of the

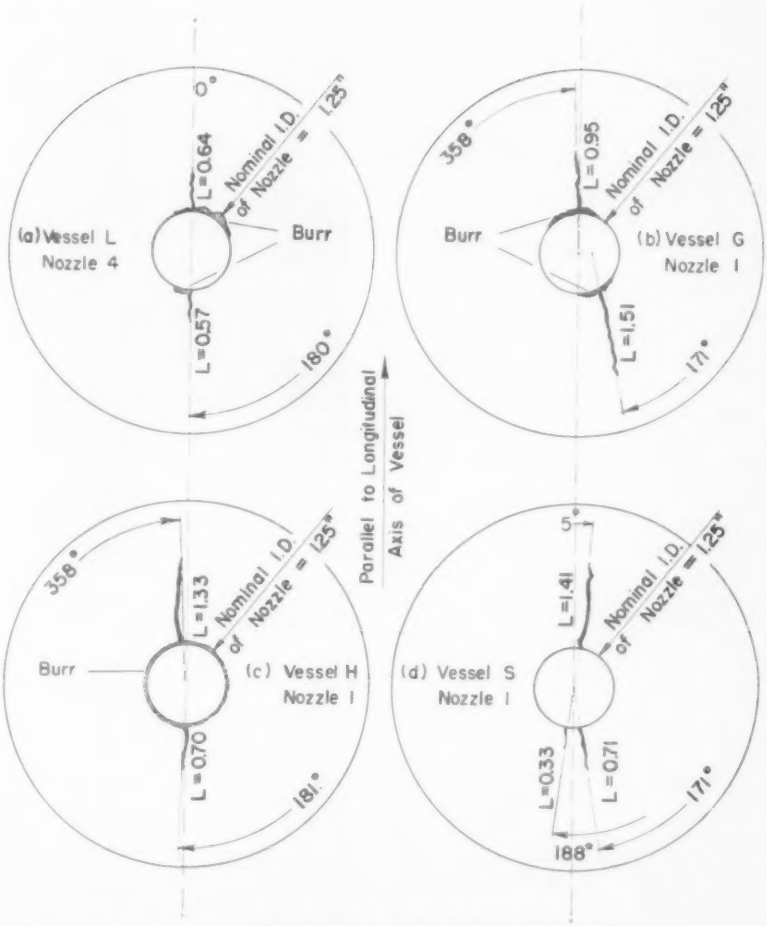


Fig. 3 Distribution of fatigue cracks in nozzles of pressure vessels

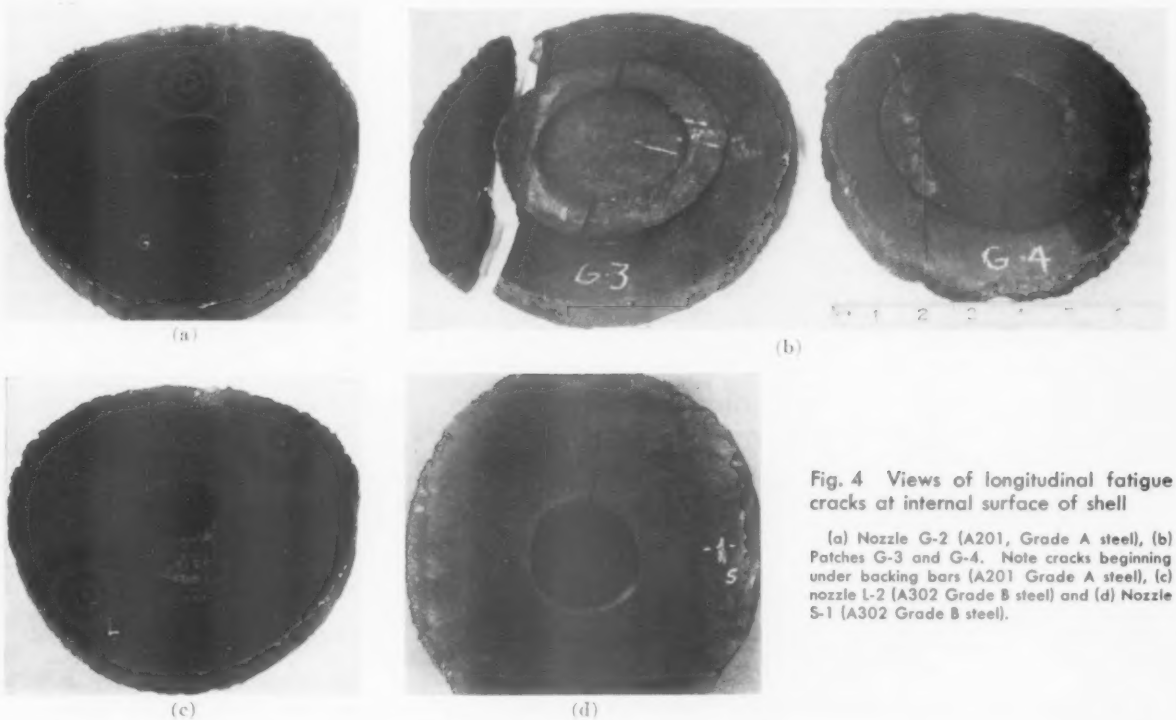


Fig. 4 Views of longitudinal fatigue cracks at internal surface of shell

(a) Nozzle G-2 (A201, Grade A steel), (b) Patches G-3 and G-4. Note cracks beginning under backing bars (A201 Grade A steel), (c) nozzle L-2 (A302 Grade B steel) and (d) Nozzle S-1 (A302 Grade B steel).

two halves of the backing bar, as shown in Fig. 4*b* for patches G-3 and G-4. It is interesting to note that all such cracks in patches of all vessels tested always occurred in the same location, that is, in a longitudinal direction, either side of the patch. See Fig. 9 of the July, 1956 paper.

Vessel "H" of A201, Grade A Steel:

The first two nozzles, H-1 and H-2, had square edges. After they had failed they were replaced by two nozzles, designated H-3 and H-4, with a $^1/_8$ in. radius, as previously described. These two nozzles have supported a far greater number of cycles than nozzles H-1 and H-2; comments on this point will be found under Vessel "M" and under "General Considerations." The fatigue test was discontinued without failure in nozzles H-3 and H-4.

Vessel "L" of A302, Grade B Steel:

Nozzles L-1 and L-2 underwent failure. Figure 4*c* shows the longitudinal cracks in nozzle L-2. The crack pattern is seen to be identical to that of nozzle G-2 of A201 steel. At this point, nozzles L-3 and L-4 were removed and were found to have partial cracks: See Figs. 2 and 3*a*.

Vessel "M" of A302, Grade B Steel:

The first two nozzles M-1 and M-2 had square edges. After they had failed, they were replaced, as in vessel "H," by two nozzles, designated M-3 and M-4, with a $^1/_8$ in. radius, as previously described. These two nozzles have supported a far greater number of cycles, which seems out of proportion, when compared to nozzles M-1 and M-2 and also when compared to results on $^1/_8$ in. radius nozzles in vessels "P" and "S" below. By analogy, the fatigue resistance of nozzles H-3 and H-4 in vessel "H," discussed above, would also appear too high: See also below, "General Considerations," for a further discussion of this point.

Fig. 5 View at plane of propagation of fatigue cracks in nozzle S-1

Vessel "P" of A302, Grade B Steel:

The two nozzles P-1 and P-2 have failed. Nozzle P-1, after being cut out of the shell, was bent in such a way as to open up the cracks and reveal the mating surfaces. Nothing, such as inclusions, porosity, etc..., was seen that could have affected its fatigue resistance.

Vessel "S" of A302, Grade B Steel:

Nozzle S-1 has failed and both nozzles S-1 and S-2 were cut out at this point with nozzle S-2 having only partial cracks.

Figure 4*d* shows the longitudinal cracks in nozzle S-1. This nozzle was also bent in such a way as to open up the cracks and reveal the mating surfaces; these are shown in Fig. 5. The manner of propagation of the cracks, starting at the edge of the nozzle hole, is very clear and is typical of all such fatigue failures. The radius wanted at the edge of the nozzle hole was $^1/_8$ in.; actually, the edge at the plane of crack had a radius of $^9/_{64}$ in. on one side and $^1/_8$ in. on the other.

After nozzles S-1 and S-2, which had a $^1/_8$ in. radius at edge, were cut out, they were replaced by two new nozzles S-3 and S-4 with a $^1/_4$ in. radius at edge; tests on these are not yet completed.

General Considerations

From the data in Table 1 that concern only nozzles that have experienced complete failure, made evident by oil leakage, a fatigue curve can be plotted giving the number of cycles to failure as a function of the maximum cyclic internal pressure applied to the pressure vessels; this is shown in Fig. 6.

It is seen that failures of nozzles L-1, L-2, M-1, P-1, P-2 and S-1, in vessels of A302, Grade B steel, lie on a smooth curve; it is interesting to note that nozzles L-1, L-2 and M-1 had square edges while nozzles P-1, P-2 and S-1 had a $^1/_8$-in. radius edge. The curve brings out the fact that nozzles M-3 and M-4 have supported an unexpectedly high number of cycles which seems out of range and that this does not appear to be entirely due to the presence of a $^1/_8$ in. radius at the edge of the nozzle hole if the very consistent results of nozzles P-1, P-2 and S-1 are taken into consideration.

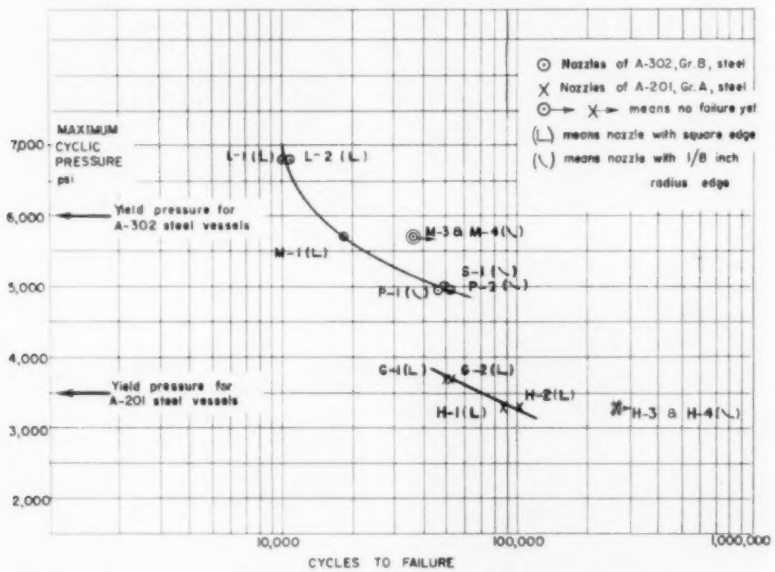
The same comments apply to nozzles H-3 and H-4 in relation with results of nozzles H-1, H-2, G-1 and G-2 in vessels of A201, Grade A steel.

One of the many possible explanations for this behavior could be found in a state of favorable residual stresses around these nozzles M-3, M-4, H-3 and H-4 brought about when they were welded in the shell in place of nozzles M-1, M-2, H-1 and H-2 which had been cut out.

Conclusions

Photographs and drawings of fatigue cracks in nozzles show that:

1. All occurred in the longitudinal direction of vessels, that is perpendicularly to the maximum stresses which are in the circumferential direction.
2. All began in the region of points A and A′ of Fig. 1 which are points of maximum circumferential stresses.
3. The crack pattern is the same whether A201 or A302 steel is tested.
4. Table 1 and Fig. 6 show that fatigue test results were quite consistent and thus should be rather reliable.



g. 6 Fatigue resistance of simulated nozzles in model pressure vessels

Welded Continuous Frames and Their Components
Progress Report No. 21

THE PLASTIC BEHAVIOR OF STRUCTURAL MEMBERS AND FRAMES

A summary report of demonstration tests conducted during the summer course, "Plastic Design in Structural Steel," presented at Lehigh University

BY GEORGE C. DRISCOLL, JR. AND LYNN S. BEEDLE

ABSTRACT. Plastic design makes available to structural engineers a new design concept based on the maximum strength of structural steel as revealed by analysis of its plastic rather than elastic behavior under load. This report describes a comprehensive series of demonstration tests which were performed to illustrate the plastic behavior of basic structural members and frames. The results of the tests gave good agreement with the simple theory on which plastic design is based.

Flexure and buckling tests were made on simple beams, a flexure test was made on a continuous beam, and short columns were subjected to combined bending plus axial load. A test was made on a full size welded connection of the type found in industrial buildings. Also, a complete gabled portal frame was tested to its ultimate load.

The results of these and many other tests of similar types lend the most convincing arguments that the maximum strength of structures may be predicted with sufficient accuracy to allow plastic design to be used with safety and confidence.

Introduction

In September 1955, a Summer Course in *Plastic Design in Structural Steel* was given at Lehigh University, sponsored by the American Institute of Steel Construction in cooperation with the American Society for Engineering Education and the Structural and Engineering Mechanics divisions of the American Society of Civil Engineers. This course was offered to educators and structural engineers in order to present a new design concept based upon the maximum strength of structural steel as revealed by analysis of its plastic rather than elastic behavior under load.

A comprehensive series of lectures covering this concept was presented.[1] To supplement the lectures, a series of tests was conducted to illustrate the principles of plastic behavior of structures. The general plan of the tests is given in Table 1 together with an indication of the principle demonstrated by each.

First, a tensile coupon test was performed to illustrate the manner in which the mechanical properties of steel are determined and to show the stress-strain characteristics of structural steel.

Then, the two basic principles of plastic analysis, plastification of cross section and redistribution of moment, were shown in a pair of beam tests. A test of a simply-supported control beam (T-1) demonstrated the additional reserve load capacity due to plastification of cross section and the ability of a beam to form a plastic hinge. A test of an indeterminate beam, continuous over two spans (T-2), showed the effect of redistribution of moment in adding to the carrying capacity of a member.

Further tests were made to point out certain modifications which must be considered in plastic design.

Plastic lateral buckling was illustrated by a test on a simple beam (T-3) loaded with two concentrated loads such that a section of constant maximum moment occurred over a length purposely made long enough for buckling to be critical. An additional test made on an identical beam (T-5) (with the exception that only a single center concentrated load was applied) showed the effect of a moment gradient in reducing the tendency toward plastic lateral buckling.

Three beam-column tests had as one of their objectives the demonstration of the reduction of plastic moment due to axial load. These test specimens were short enough so that buckling would not be a factor. The first of these tests was a direct axial load test (T-6) on a short column to obtain the compressive properties of the section and show its load-carrying capacity in the absence of bending moment. The second test was a column (T-7) loaded with small eccentricity to show the effect of high axial load on plastic bending. Specimen (T-8) was loaded with a direct load at very large eccentricity to produce a case with larger bending moment and smaller axial load.

These three tests, plus the test of the control beam taken from the same material, made it possible to show how the presence of direct stress affects the ability of a structural member to develop the plastic moment.

The test of a welded corner connection was performed to demonstrate the ability of this important structural component to behave as assumed in the theory. A square connection (T-4) of the type which might be found in a flat-roofed building frame, was fabricated from 30-in. wide-flange shapes. In loading the connection in such a manner as to cause closing of the corner, the ability of a large size rolled section to develop a plastic hinge under combined bending and axial load was shown.

The final demonstration was a full-scale test of a 40-ft span gabled portal frame (T-9) subjected to vertical roof loads and horizontal loads simulating the action of wind. In this test there was opportunity to observe most of the major points emphasized in the lectures,[1] including formation of plastic hinges, redistribution of moment, effect of axial forces, magnitude of lateral support forces, effect of lateral buckling, appearance of the structure at working,

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American Iron and Steel Institute
Institute of Research, Lehigh University
Office of Naval Research (Contract No. 61003)
Bureau of Ships
Bureau of Yards and Docks

Table I—General Plan of Demonstrations

Test	Sketch	Principle Demonstrated
P-2 Tensile coupon	18" G.L.	Manner of determining mechanical properties
T-1 Control beam	12' 12 WF 36	Plastification of cross section
T-2 Continuous beam	10' 10' 12 WF 36	Redistribution of moment
T-3 Lateral buckling beam	15' 14 WF 38	Lateral buckling of long laterally unsupported beam
T-5 Centrally loaded beam	15' 14 WF 38	Effect of moment gradient in reducing tendency toward plastic lateral buckling
T-6 Cross section	3' 12 WF 36	Compressive properties of steel
T-7 Eccentrically T-8 loaded beam-column	3' 12 WF 36	Reduction of plastic moment due to axial load
T-4 Corner connection	15 1/2' 30 WF 108	Behavior of corner connection
T-9 Gabled portal frame	40' 10' 6 2/3' 12 WF 36	Behavior of complete portal frame

yield and ultimate loads, and accuracy of calculation of important results.

The general plan of the demonstration tests is given in Table 1 which lists each test, shows a schematic diagram of the test and indicates the principle illustrated by each. In the following sections, a detailed description of each test is given, including a discussion of the results.

Determination of Material Properties

Three different wide-flange rolled shapes were used in the test specimens. These were the 12WF36, 14WF38, and 30WF108 sections. The cross-sectional dimensions of each were measured and recorded for comparison with handbook values and for use in calculating predicted loads. A summary of these values is shown in Table 2.

To obtain the mechanical properties of the steel used, tensile coupons from each section were tested. The specimens were machined from the web and flanges of the rolled sections in the shape ordinarily used for plate specimens.

The specimens were tested with flat wedge grips in a 60,000-lb capacity hydraulic universal testing machine. Load and elongation over an 8-in. gage length were measured and plotted by means of a low-magnification automatic stress-strain recorder. This instrument could record strains well into strain hardening without resetting, but the strain readings were not precise enough to permit calculation of the modulus of elasticity.

The rate of application of load was about 30 micro inches per in. per sec, in the plastic range, a rate much lower than the usual standard mill test rate (As will be evident later, there was some variation in the loading rate.) This reduced rate of loading was used because the results were to be used to predict values for static tests where equilibrium of load and deformation would be obtained at each load increment before readings would be taken.

A unique feature of these tests was the taking of "static yield load" readings in the yield range. After the yield region had been reached, but before strain hardening had commenced, the strain rate was reduced to zero for a period of a few minutes to allow the load to reach an equilibrium point. The technique used to accomplish this was to mount a dial gage between the fixed and the moving cross heads of the testing machine. The loading valve was closed until the *increase* in deformation and the *decrease* in load both approached zero. "Static" readings were then taken. From this reading the lowest possible yield stress could be calculated, thus insuring that in the actual test structure the yield stress would be equal to this or greater. In Figs. 1 to 4, the yield levels at different strain rates as well as at zero strain rate are indicated.

All other usual data such as ultimate load, per cent elongation, and reduction of area, were taken.

Stress-strain curves of all tensile specimens tested are shown in Figs. 1, 2 and 3. A more detailed curve of coupon P-2 is shown in Fig. 4, which points out the static yield readings and the yield stress levels at different strain rates. The results of the tests are summarized in Table 3.

These coupon stress values, together with the measured cross section dimensions shown in Table 2, were used to calculate the theoretical curves shown on each plot of test results.

Plastification of Cross Section (Test T-1)

Since several of the demonstration

Table 2—Section Properties of Test Specimens

			Flange			Axis x-x			
Section	Area of section, A, in.^{2}	Depth of section, d, in.	Width, b, in.	Average thickness, t, in.	Web thickness, w, in.	I in.^{4}	S in.^{3}	Z in.^{3}	f
30WF108									
Handbook	31.77	29.82	10.484	0.760	0.548	4461.0	299.2	345.5	1.16
Measured	30.46	29.93	10.460	0.740	0.518	4345.8	290.3	334.1	1.15
% Variation	−4.12	+0.37	−0.23	−2.63	−5.46	−2.58	−2.98	−3.30	−0.86
14WF38									
Handbook	11.17	14.12	6.776	0.513	0.313	385.3	54.6	61.9	1.13
Measured	10.83	14.07	6.880	0.486	0.313	369.5	52.5	59.12	1.13
% Variation	−3.22	−0.35	+1.51	−5.26	0.000	−4.10	−4.00	−3.85	0
12WF36									
Handbook	10.59	12.24	6.565	0.540	0.305	280.8	45.9	51.42	1.12
Measured	10.78	12.30	6.625	0.514	0.337	282.1	45.9	51.79	1.13
% Variation	+1.79	+0.49	+0.91	−4.81	+10.50	+0.46	0	+0.72	+0.89

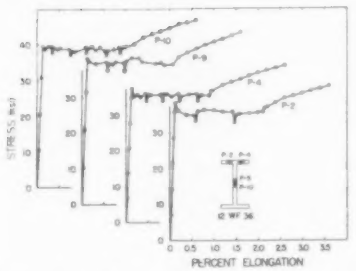

Fig. 1 Tensile coupon tests for 12WF36

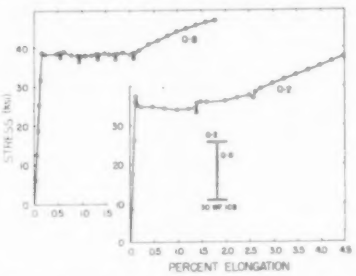

Fig. 2 Tensile coupon tests for 30WF108

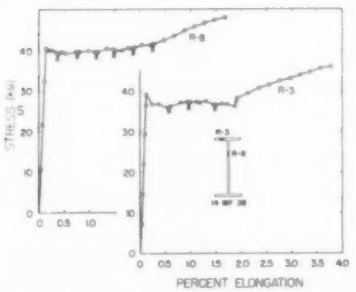

Fig. 3 Tensile coupon tests for 14WF38

structures were to be fabricated from 12WF36 sections, a length of this section was tested as a control beam to obtain the relationship between moment and curvature under pure bending. The reserve of moment above the yield point due to plastification of the cross section was the other important phenomenon demonstrated by this test.

The specimen tested was a 13-ft length of 12WF36 with vertical stiffeners welded at support and load points to prevent web crippling (Fig. 5). A 300,000-lb hydraulic universal testing machine was used to apply load to the specimen supported on rollers at a 12-ft span. A heavy 14-in. wide-flange section was used as a base beam to carry the reactions of the specimen to the testing machine table. Loads were applied at third points of the span using a spreader beam to distribute the testing machine load to two rollers.

Instrumentation used to measure the important deformations consisted of an automatic plotting board,* plotting load versus center deflection; a rotation indicator, measuring rotation in the maximum moment section; and a dial indicator, recording the center deflection.

Load was applied continuously at a moderate rate which allowed gage readings to be taken and the data plotted without interrupting the loading. After the plastic range had been reached, it was necessary to halt the application of load twice to allow dial indicators to be reset. At these points a short time was taken to allow the load and strains to reach equilibrium before the resets were made.

Loading was continued until the ultimate load was reached, followed by a gradual drop in load when deformations had become so great as to cause lateral instability. Figures 8 and 9 show the beam under test before and after yielding.

* Certain instruments used on the different tests are described in detail in the Appendix.

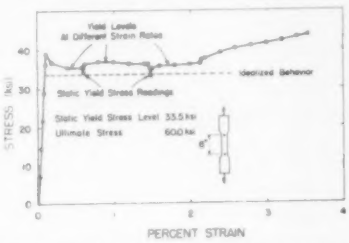

Fig. 4 Tensile coupon test for 12WF36

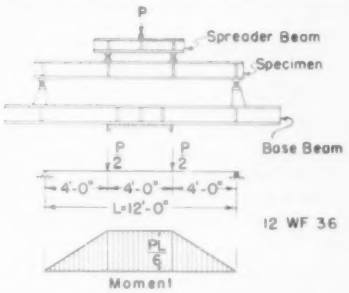

Fig. 5 Setup for control beam test (T-1)

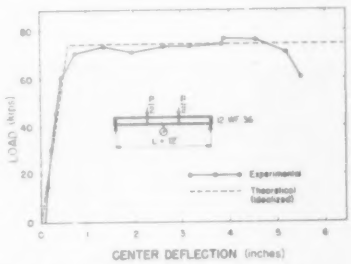

Fig. 6 Load-deflection curve for control beam test (T-1)

Table 3—Summary of Coupon Test Results

Material				Average Coupon Test Results						
Coupon Number	Shape	Location	Type Coupon	σ_{yst} (ksi)	σ_{yu} (ksi)	σ_{yL} (ksi)	σ_{ult} (ksi)	ϵ_y (in./in.)	ϵ_{st} (in/in)	E_{st} (ksi)
P-2	12WF36	Flange	Tension	33.7	38.6	36.0	60.0	0.00129	0.0213	511
P-4	"		"	34.2	37.8	36.2	59.5	0.00142	0.0190	436
P-9	"	Web	"	37.7	41.3	39.8	64.7	0.00142	0.0206	468
P-10	"		"	38.1	39.4	38.6	62.1	0.00137	0.0180	515
R-3	14WF38	Flange	"	35.6	39.2	36.0	61.2	0.00150	0.0190	512
R-8	"	Web	"							
			"	39.2	40.9	39.7	63.8	0.00175	0.0180	546
Q-2	30WF108	Flange	"	33.1	36.9	34.8	60.6	0.00137	0.0200	479
Q-8	"	Web	Tension	37.6	39.1	38.1	62.2	0.00175	0.0205	577

σ_{yst} = Static yield level.
σ_{yu} = Upper yield point.
σ_{yL} = Lower yield point.
σ_{ult} = Ultimate tensile strength.
ϵ_y = Initial yield strain.
ϵ_{st} = Strain at initiation of strain hardening.
E_{st} = Strain hardening modulus of elasticity.

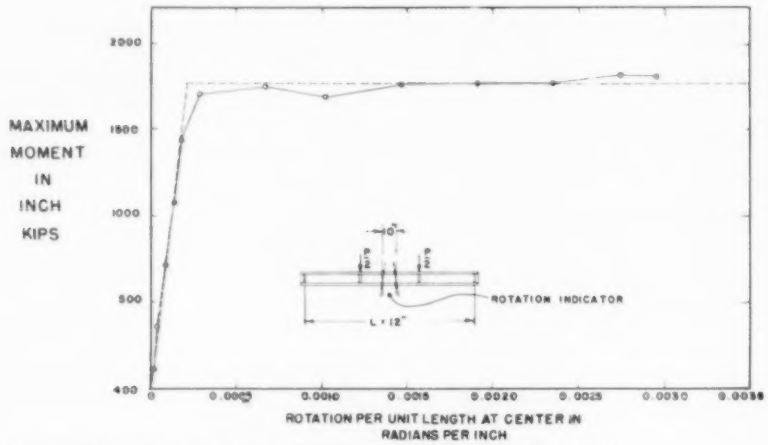

Fig. 7 Moment-curvature relationship for control beam test (T-1)

A load-deflection curve for the control beam is shown in Fig. 6, and an M-ϕ curve is shown in Fig. 7. These two curves demonstrate that the simple plastic theory is a reliable basis for predicting the behavior of a beam in bending.

Redistribution of Moment (Test T-2)

A two-span continuous beam, statically indeterminate to the first degree, was tested to show the increase in ultimate load above that at first yield, an increase achieved as a result of redistribution of moment combined with plastification of cross section.

The beam was symmetrically loaded at the third-points of two 10-ft spans (Figs. 10 and 15). The center support was a fixed rocker and the two end supports were expansion rockers. Two 100-ton hydraulic bridge jacks were used for loading. Each was supported on a spreader beam which distributed the load to two points by means of rollers. Each jack reacted against a frame consisting of a cross beam and two 3-in. diam steel rods anchored to the test floor of the laboratory. SR-4 gages attached to each of the four tie rods converted them to dynamometers, allowing the loads to be read to greater accuracy and sensitivity than permitted by the pressure gage of the jacks. The beam setup may be seen in Fig. 15.

Lateral support was provided for the compression flange of the beam at the load-points by means of 6-in. light beam sections welded to the web stiffeners (Fig. 14). Lateral reaction was furnished by a beam fastened to the wall of the laboratory. The magnitude of the lateral reaction for each beam was measured by a flexible aluminum dynamometer which also allowed vertical deflection of the lateral support beams without giving restraint to the vertical deflection of the beam specimen. Lateral support of the compression flange of the beam at the support points was provided by friction on the supports.

Vertical deflection was measured at one of the outer load-points, and rotations were measured across the plastic

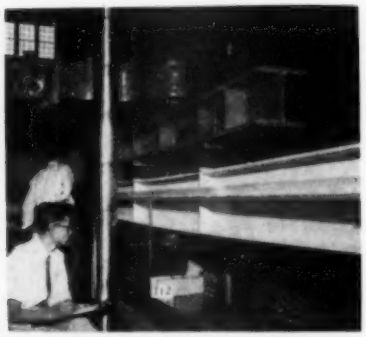

Fig. 8 Since several of the demonstration structures were to be fabricated from 12WF36 sections, a length of this section was tested as a control beam . . . . . .

Fig. 9 . . . . . and it showed how a plastic hinge is developed in a wide flange section

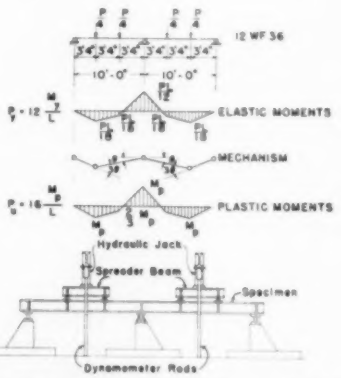

Fig. 10 Setup for continuous beam test (T-2)

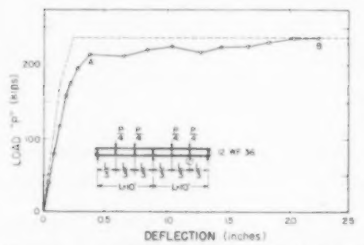

Fig. 11 Load-deflection at right-hand load point for continuous beam test (T-2)

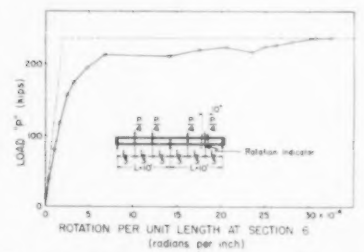

Fig. 12 Load versus unit rotation at right-hand load point of continuous beam (T-2)

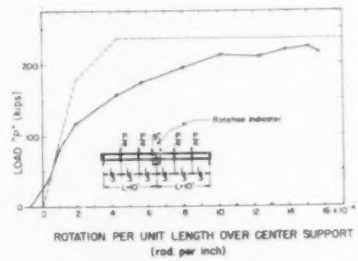

Fig. 13 Load versus unit rotation at center support of continuous beam (T-2)

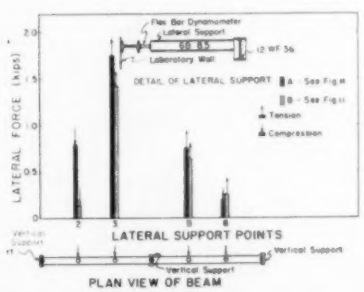

Fig. 14 Lateral support forces on continuous beam (T-2)

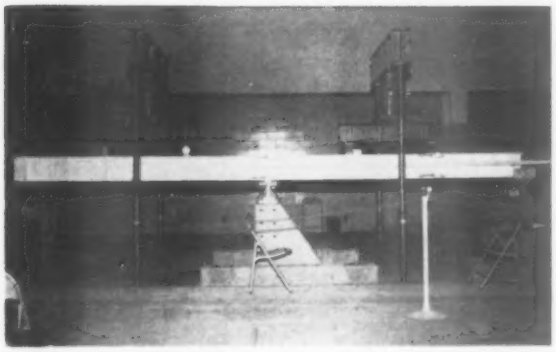

Fig. 15 A continuous beam was tested to show how redistribution of moment affects the carrying capacity of an indeterminate structure

Fig. 16 High shear stresses near the center support caused premature yielding and excessive deflection in the elastic range, but the predicted ultimate load was attained

hinges at the center support and one of the outer load-points (Fig. 17).

Load was applied by hand-pumping of the hydraulic jacks and stopped momentarily to take readings of the instruments. Loading was continued until the maximum had been reached and started to drop off, after which the test was discontinued since further deformation served no useful purpose.

Results of the continuous beam test are shown in Figs. 11, 12, 13, and 14. The load-deflection curve of the beam is shown in Fig. 11. The rotations at the two plastic hinges are plotted in Figs. 12 and 13. In Fig. 14 are shown the forces in the lateral supports at each point of load application.

It may be noted that the agreement between the theoretical curves and the experimental results is much poorer in this test than for the control beam test.

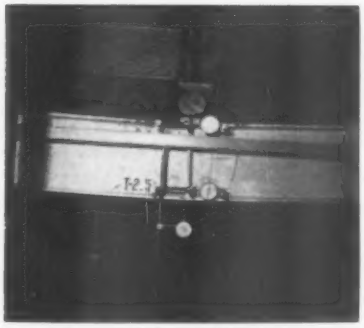

Fig. 17 A rotation indicator was used to measure the rotation over a short length of the beam near the plastic hinge

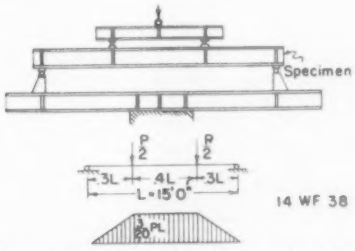

Fig. 18 Setup for lateral buckling beam test (T-3)

This may be attributed not to a shortcoming of the theory, but to lack of application of known theory.

The difference lies in the neglect of the effect of shear on deflection. In the control beam test, the nominal web shear stress at ultimate load was about half the shear yield stress. Therefore the shear deflections would be small, and neglecting them (as is customary) causes no serious discrepancy. However, in the case of the continuous beam test, it was necessary to change the spans originally planned to shorter spans because of limitations of the testing equipment. This created a situation in which the shear stresses, even in the elastic range, were sufficient to cause deflections of the same order of magnitude as the flexural stresses. In addition, a maximum principal shearing stress equal to the shear yield stress could be predicted near the center support at a load of about 143 kips, or less than the yield load in flexure. Naturally the reduced shearing rigidity at loads above this point could be expected to result in larger deflections than those calculated by considering bending alone. The flaking of mill scale due to shear yielding is quite prominent in Fig. 16.

It is quite significant, however, that despite the premature shear yielding, the continuous beam eventually managed to carry its predicted ultimate load (Fig. 11).

Another interesting result obtained in this test is the magnitude of the lateral support forces. In Fig. 14, bar graphs show the lateral support force at each of the load points for two different load conditions typical of the plastic range. Load condition "A" indicates the lateral support forces at the formation of the final mechanism and load condition "B" shows the lateral support forces after the mechanism has deflected six times as much as at "A," while continuing to maintain and even increase the load on the beam. Markings on Fig. 11 show the relative locations of these lateral support readings in the load-deflection history of the beam.

Of importance is the fact that at both readings, the loads in the lateral supports were no greater than a maximum of 1750 lb, indicating that adequate support could be provided by very light members, probably limited in size by slenderness more than by load.

Lateral Buckling of Beams (Tests T-3 and T-5)

In order to show the effect of lateral buckling on beams loaded into the plastic range, two 14WF38 beams of 15-ft span were tested in bending.

The first of these beams, T-3, was loaded with two concentrated loads centered 6 feet apart (Figs. 18 and 21). The second beam, T-5, was loaded with a single concentrated load applied at the center (Figs. 23 and 25).

These two loading conditions offered an opportunity to observe the effect of unsupported length and moment gra-

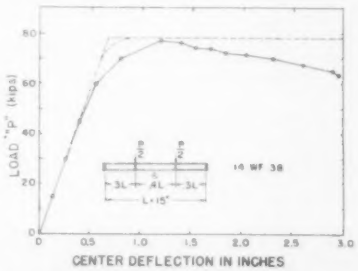

Fig. 19 Load-deflection curve of beam with uniform moment which failed by lateral buckling (T-3)

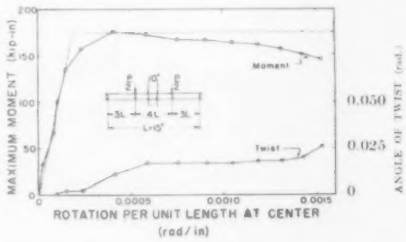

Fig. 20 Moment-curvature and twist-curvature diagram for beam (T-3)

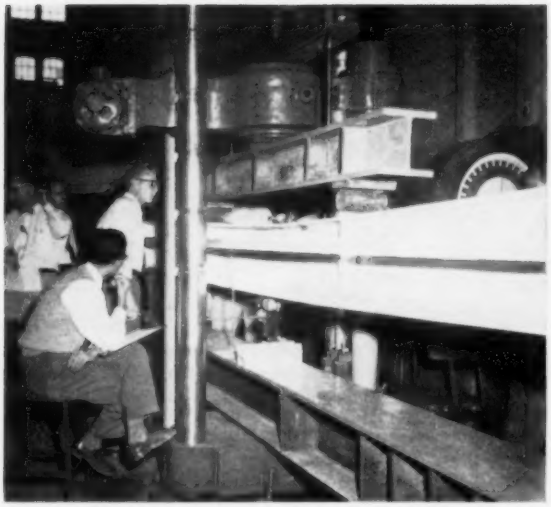

Fig. 21 Applying load over an unsupported span too long to prevent premature buckling.....

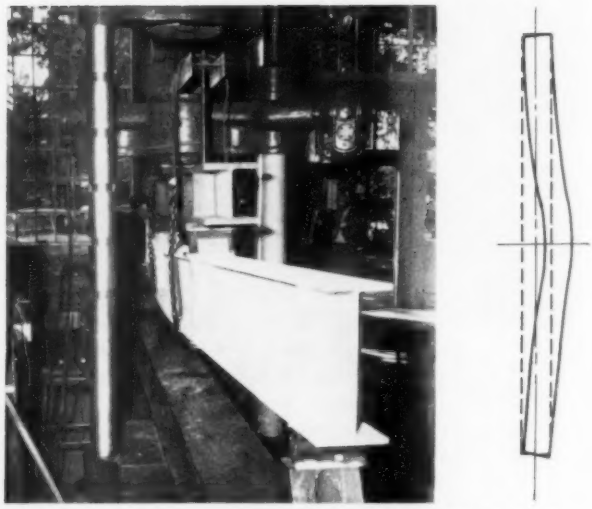

Fig. 22 .....caused severe lateral deformation of a beam

dient on lateral buckling. In test T-3, the 6-ft spacing between load points constituted an unsupported length short enough so that buckling would not occur in the elastic range, but long enough so that it would occur once the plastic moment had been reached. It should also be noted that the portion of the beam between load points was a zone of constant bending moment—a most severe condition. The second beam (test T-5) was unsupported between the load point and the end supports. Thus its laterally unsupported length was actually 18 inches longer than that of beam T-3. However, there was a steep moment gradient along its entire length in contrast to the zone of contrast moment on beam T-3.

Both beams had vertical web stiffeners welded at load and support points. Forces at load and support points were transmitted through rollers to reduce frictional restraints as much as possible.

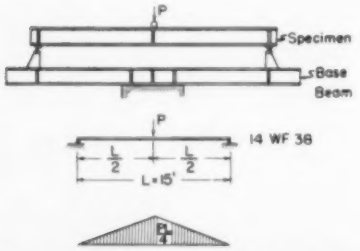

Fig. 23 Setup for centrally loaded beam test (T-5)

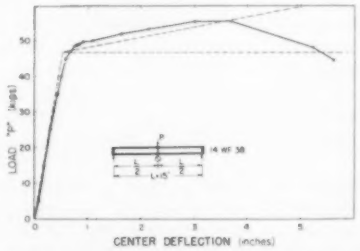

Fig. 24 Load versus center deflection curve for centrally loaded beam (T-5)

Instrumentation included a center deflection gage, rotation indicator, and the plotting board—the same as was used in the control beam test (T-1). In addition, a twist indicator was added to aid in the detection of lateral buckling.

Conduct of the test in both cases was essentially the same as in the control beam test (T-1), with load being applied continuously at a rate slow enough to allow readings of all the instruments to be taken at intervals until the test was completed.

As is shown in the M-ϕ curve for T-3 (Fig. 20), the beam with the constant moment section reached its ultimate moment after rotating about two times the curvature at first yield (ϕ_y) and then the moment began to drop. This drop in moment immediately after the formation of the mechanism coincided with a rapid increase in lateral twist. In contrast to this it will be noted that load did not drop off in test T-1 until about 10 times ϕ_y, even though that beam also had a section of constant

Fig. 25 When a central concentrated load was applied to a beam of the same size as the lateral buckling beam .....

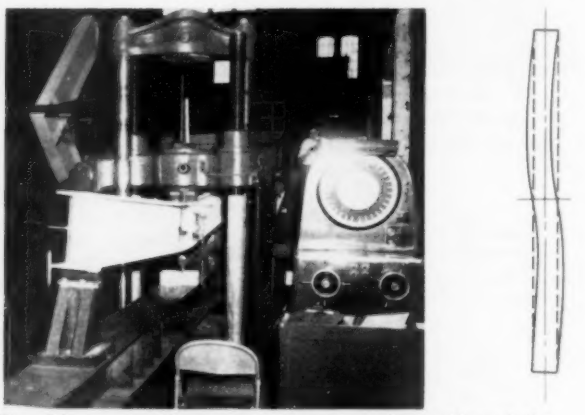

Fig. 26 .....the steep moment gradient allowed the load to exceed the predicted ultimate load as a result of strain hardening

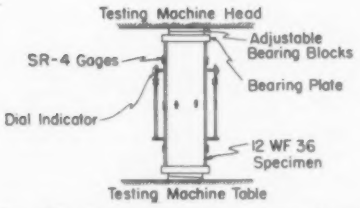

Fig. 27 Stub column (cross section) test setup (T-6)

moment. Though twist was not measured in test T-1, past experience indicates that measurements would have shown that it would not begin to twist rapidly until it neared the larger ϕ-value which was reached before the drop in load.

Thus, comparison of the curves in Figs. 19 and 20 with the corresponding curves for the laterally stable control beam (T-1) shown in Figs. 6 and 7 immediately demonstrates the effect of a long laterally unsupported span.

Figure 24 presents the load versus center deflection curve of the centrally loaded beam, T-5. Though this beam was identical to specimen T-3 which buckled as soon as the mechanism formed, it passed its predicted maximum load and continued to increase in load at a uniform rate. This increase in load was achieved even though specimen T-5 had an even greater unsupported span than T-3.

The factor which produced this added resistance to lateral buckling was the steep moment gradient resulting from the application of a single concentrated load. The steep moment gradient caused strain hardening to take effect immediately after the plastic moment was reached rather than after additional deflection as occurs in a long section of constant moment.

The two dashed lines in Fig. 24 compare the trend of the load-deflection curve predicted by considering strain hardening with that neglecting strain hardening. The agreement with the former is excellent.

The buckled shapes of the members are shown in Figs. 22 and 26. The beam with the constant moment zone buckled symmetrically in a single wave,

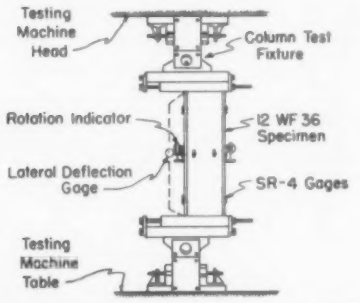

Fig. 28 Beam-column test setup (T-7, T-8)

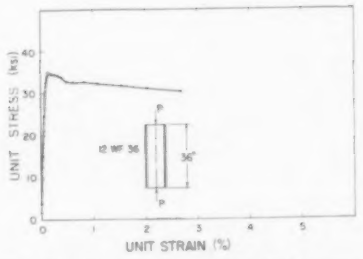

Fig. 29 Compression stress-strain curve of 12WF36 stub column (T-6)

while the centrally loaded beam buckled antisymmetrically in two waves.

Compressive Properties of Steel (Test T-6)

A "cross-section" (stub-column) test was made to find the compressive stress-strain curve of a full cross section of the 12WF36 material used for many of the test specimens. This was an axial compression test which gave the integrated effect of different web and flange strengths in one test. The main purpose of the test was to obtain a compressive yield value to use in predictions for eccentrically loaded compression tests.

The specimen was a 3-ft length of rolled section with both ends milled parallel in planes perpendicular to the centroidal axis. The short length was used to keep the L/r ratio below 25, reducing the tendency toward lateral buckling.

An 800,000-lb screw-type universal testing machine was used for loading. Adjustable bearing blocks were used to furnish flat bearing for the ends of the specimen (Fig. 27). Several SR-4 strain gages and two dial indicators, fastened to lugs welded on 20-in. gage lengths, were provided for the measurement of strains. Prior to the stress-strain test, the specimen was aligned to insure concentric loading.

In the stress-strain test of the cross section, load was applied in selected increments until yielding occurred. Thereafter, further straining was controlled by limiting the magnitude of strain increments. Loading and straining were halted long enough to take readings of the several measurements at each of these increments. Loading of the specimen was continued past the ultimate load until buckling of web and flanges caused the load to show a definite downward trend.

In Fig. 29 is shown the stress-strain curve of specimen T-6, the cross-section specimen. The yield stress level from this curve served as the level to be used in calculating axial loads for the beam-column tests which followed.

The result of the cross-section compression test was slightly lower than that predicted (about 5%), using the weighted average of two web and two

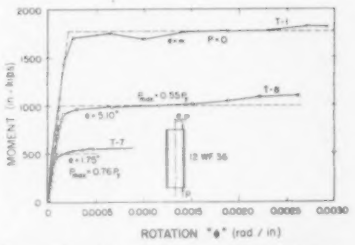

Fig. 30 Moment-curvature diagrams for beams with different axial loads

flange tensile coupons.

The maximum load in this test is used to signify a P/P_y value of 1 in the interaction curve shown in Fig. 31a.

Reduction of Plastic Moment Due to Axial Load (Tests T-7 and T-8)

Two compression members were tested with the loads applied at eccentricities such that, in effect, the tests were bending tests with high axial loads. Through the results of these tests, it was intended to show the effect of axial load on the plastic moment.

The specimens used were the same size as the cross-section specimen previously tested, being 3-ft lengths of 12WF36. Since a component of tensile force was to be expected in a bending test, it was necessary to weld end plates to the specimens. The distinguishing feature between the two tests was that

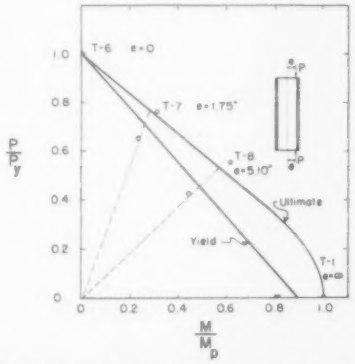

Fig. 31a Interaction curve for wide-flange beam columns

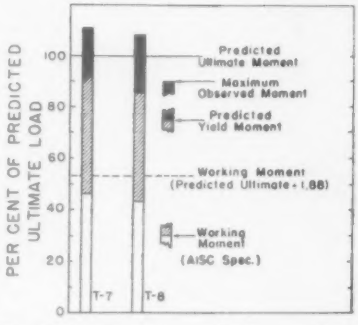

Fig. 31b Bar chart of beam-column strengths

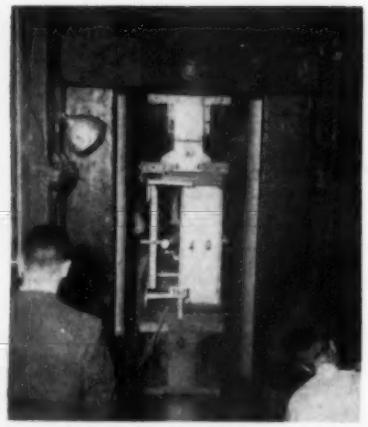

Fig. 32 By using special column testing fixtures, an eccentric compression load was applied to a short section of 12WF36

T-7 was to have an eccentricity of 1.75 in. and T-8 an eccentricity of 5.10 in.

Special column testing fixtures were used to hold the specimens in position for the proper application of loads (Fig. 28). These fixtures allowed rotation of the ends in a pin-ended condition in the plane of bending, but held the ends fixed against rotation perpendicular to that plane. For each beam-column test, the assembly of specimen and end fixtures was mounted in an 800,000-lb screw-type universal testing machine (Figs. 32 and 33).

On each test, the specimen was equipped with a number of SR-4 gages for strain measurement and alignment, a rotation indicator, and dial gages for measuring center deflection. Prior to the start of the ultimate load test, an alignment procedure was carried out to insure that the eccentricity at each end of the specimen was equal.

In the actual test of each specimen, the usual procedure followed in tests to be carried through the plastic range was used. Increments of load were applied and data taken at planned intervals; after yield had occurred, "load" criterion was changed to a "deflection" criterion. Deformation was continued until the maximum load was passed and the specimen was showing definite signs of reduction of load capacity.

Figure 30 compares the moment versus ϕ curves for the three bending members of 12WF36 section which were tested with different amounts of axial load. Here may be seen the effect of axial load in reducing plastic bending moment. For the case of test T-1, the axial load was zero. For the other cases where the member was loaded as an eccentrically loaded column, the larger the eccentricity, the smaller the axial load accompanying formation of a plastic hinge.

Examination of the white wash patterns in Fig. 33*a* caused by flaking of the mill scale, gives an indication of the change in the neutral axis resulting from changes in the eccentricity.

In Fig. 31*a* is shown the theoretical interaction curve of moment versus axial load calculated from equations 9.10 and 9.11 of reference 1. The experimental results at ultimate load and yield load are plotted for comparison. Also shown here are bar graphs of tests T-7 and T-8, indicating working loads compared with theoretical yield and ultimate loads, and also with the experimental ultimate loads (Fig. 31*b*). Although experimental yield occurred below predicted yield, the ultimate moments exceeded the predicted moments.

Behavior of a Corner Connection (Test T-4)

In testing a corner connection made from 30WF108 members, the opportunity was presented to observe the behavior of a fair-sized fabricated structural component. The manner of testing the connection introduced the effects of axial load with bending moment, bending with moment gradient, and magnitude of lateral support forces into the testing program. The test was similar in type to many which are reported in the earlier Lehigh work.[2]

The specimen tested was a square corner connection of a type which could be used in framing a flat-roofed industrial building. The rolled sections joined were carried a distance of about four times the beam depth outside the knee. Six-inch diameter rollers were welded to the ends of these members to act as bearing surfaces.

Figures 34 and 38 show the position in which the specimen was erected in an 800,000-lb screw-type universal testing machine. When the specimen was in this position, vertical motion of the testing machine head would apply a force which caused stresses on the knee that could be considered as a resultant of shear, axial force and bending moment in proportions typical of those found in rigid portal frames. To stabilize the structure against lateral deflection, tie rods hinged to outriggers fastened to the testing machine columns were attached at the inner and outer corners of the knee (Fig. 37). Dynamometers for measuring the lateral forces were a part of the tie rods.

In addition to using the plotting board to graph load against deflection across the ends of the legs, instruments were mounted for measuring the rotation of the knee and the forces in the lateral supports.

Testing was done in the fashion described for the preceding tests. After the ultimate load was reached, local buckling appeared in the web and com-

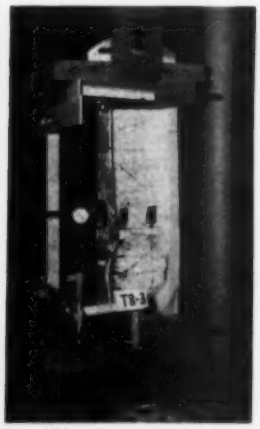

Fig. 33 The results of the test showed the effect of axial load on plastic bending moment

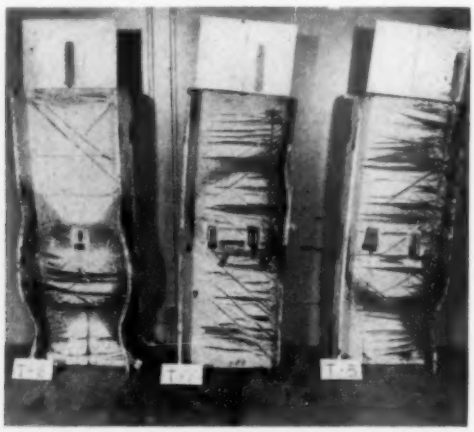

Fig. 33a An axial cross section test of a 12WF36 section was made to obtain the compressive properties, and two other members were loaded eccentrically to show the effect of axial load in reducing the plastic bending moment

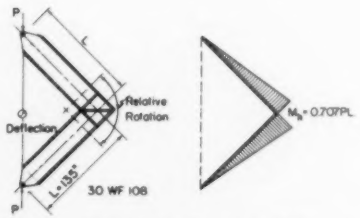

Fig. 34 Schematic diagram of corner-connection test setup (T-4)

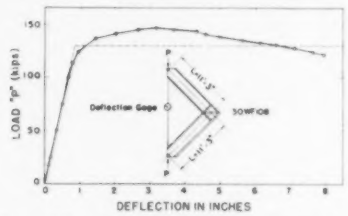

Fig. 35 Load-deflection curve for corner connection (T-4)

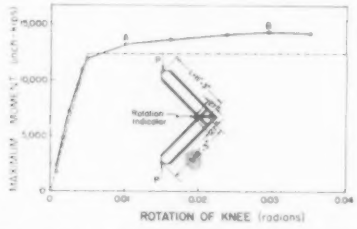

Fig. 36 Moment-rotation curve for corner connection (T-4)

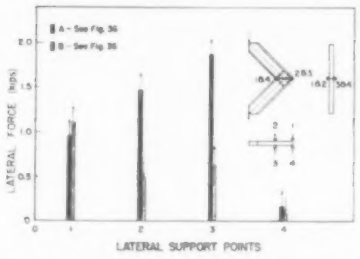

Fig. 37 Lateral support forces on corner connection (T-4)

pression flange (Fig. 39). However, the connection was able to deform considerably more at near maximum load. After the connection had been deformed beyond usefulness, it finally buckled laterally and the test was stopped.

The load-deflection curve of the connection is shown in Fig. 35, and the moment versus knee rotation curve is shown in Fig. 36. It will be noted that after the mechanism had formed as indicated by the letter "A," the load increased at a uniform rate until a maximum indicated by "B" was reached. This increase in load may be attributed to the strain hardening effect which was hastened due to the steep moment gradient in the same way as in the test of a centrally loaded beam (T-5).

In Fig. 37 are plotted the forces in the lateral support tie rods at the time the mechanism was being formed and at the ultimate load. The required lateral support force again proved to be very small in proportion to the load on the specimen.

Behavior of a Gabled Portal Frame

The 40-ft single span gabled portal frame combined a display of all the principles covered in the earlier tests. It was a welded fully-rigid structure fabricated from 12WF36 members with layout and dimensions as shown in Fig. 40. The column bases were welded to $2^1/_2$ inch thick end plates and bolted to the test bed floor of the laboratory with two 3-in. studs in each plate.

Lateral support was furnished at points 4, 5, A, 6, 7, 8, B, 9 and 10 shown in Fig. 41, by means of light beams simulating purlins. These purlins were fastened by flexible aluminum bars at their far ends to spreader beams attached to the wall columns of the laboratory.

Hydraulic tension jacks bolted to the test bed floor were used to apply a combination of vertical and horizontal loads through a system of linkages. Four vertical loads and two horizontal loads were programmed to be approximately proportional to the loads which would exist with 60 psf vertical load and 20 psf horizontal load on a building with 18-ft bay lengths. Figures 46 and 47 show the frame during erection before and after the loading equipment was installed.

Various instruments were used to measure the behavior of the structure. A surveyor's transit focused on a 1/100th in. scale suspended from the peak of the gable was used to measure the vertical deflection. The horizontal deflections of the two knees were obtained from 1/100th in. scales measuring the movement of plumb lines suspended from the knees. Rotation indicators at points 1, 4, 6, 8, 10 and 11, (Fig. 41) measured the rotations at these important points. The magnitudes of the applied loads were measured by aluminum tube dynamometers, and the lateral support forces in purlins 4, 5, 7, 9 and 10 were measured by dynamometers on the flex bars. A curve of vertical deflection of the roof peak versus load was plotted by the automatic plotting board in order to keep the audience posted on the progress of the test.

Fig. 38 Application of load to legs of the 30WF108 corner connection caused a combination of thrust, shear and bending moment at the knee

Fig. 39 After the ultimate load on the connection was reached, local buckling appeared in the web and compression flange

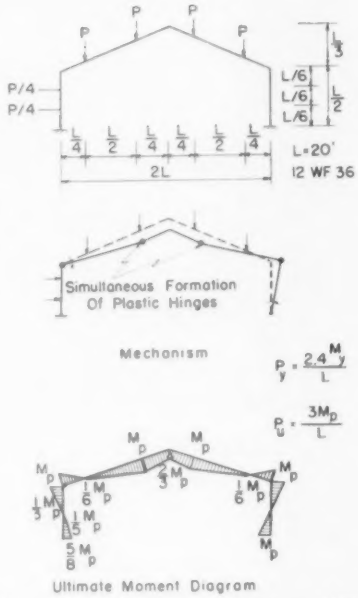

Fig. 40 Schematic diagrams for gabled portal frame (T-9)

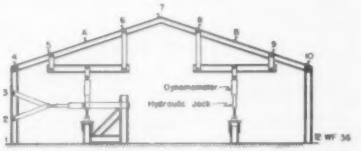

Fig. 41 Setup for gabled portal frame test (T-9)

The test was carried on with a squad of pumpers applying and maintaining the loads by hand while gage readers mounted on ladders and scaffolds took data at each load point. Views of the frame and testing equipment at different stages of the test are given in Figs. 48 through 51.

The test was carried to the ultimate load (accompanied by the formation of a mechanism) and continued far beyond this point until a combination of lateral buckling of the frame and buckling of one of the lateral support flex bars indicated that further deformation might endanger personnel. At this point, the load was still at the maximum value and the deflection about twice that at ultimate load. In Figs. 52 and 53, the appearance of two of the plastic hinges is shown at the finish of the test. Though considerable yielding is apparent, it is obvious that formation of the mechanism did not constitute a catastrophic collapse.

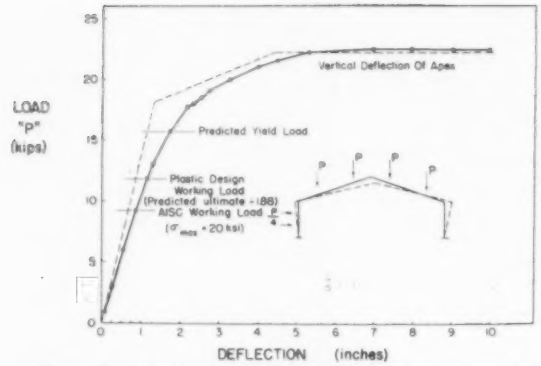

Fig. 42 Load versus center deflection curve for gabled portal frame (T-9)

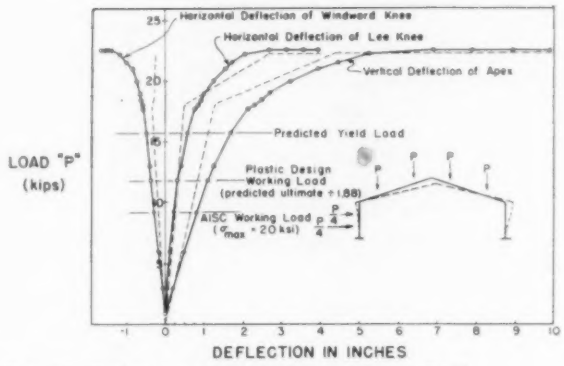
Horizontal Deflection of Windward Knee
Horizontal Deflection of Lee Knee
Vertical Deflection of Apex
Predicted Yield Load
Plastic Design Working Load (predicted ultimate ÷ 1.88)
AISC Working Load
LOAD "P" (kips)
DEFLECTION IN INCHES

Fig. 43 Deflections of gabled portal frame (T-9)

Experimental results of the gabled portal frame test are shown in Figs. 42 through 45. The horizontal deflections of the knees and the vertical deflection of the peak of the frame are compared with the approximate theoretical curves in Fig. 43. The observed ultimate load was 1% greater than predicted.

Figure 44 shows the rotation of the lee knee which was the location of the first plastic hinge and therefore the most strained part of the frame. In this curve, as in the others, the region of greatest deviation from the theoretical prediction is in the early stages of yielding, in other words, in the region where residual stresses are known to exhibit their greatest effect.

Summary and Conclusions

The following statements summarize the principles of plastic behavior of structural steel members and frames as demonstrated by the tests conducted:

1. Test of a "coupon" of structural steel verifies that its stress-strain relationship up to strain-hardening may be characterized by two straight lines, one at a slope E in the elastic region, while beyond that (in the plastic region) deformation occurs at constant stress (σ_y) until the strain is about 15 times the elastic limit strain (Fig. 4).

2. On the basis of the "static rate" yield level determined from coupon tests, the moment-rotation relationship of a beam and the resulting load-deflection curve may be determined with satisfactory accuracy (Figs. 6, 7).

3. Properly-proportioned members and components will develop the "plastic hinges" that are essential to a realization of ultimate load. Adequate "rotation capacity" was obtained in such members (Figs. 7, 24, 36).

4. As would be expected, a beam loaded so as to produce plastification over a considerable distance between points of lateral support may buckle laterally causing a reduction of load-carrying capacity and rotation capacity (Figs. 19, 20). A steep moment gradient on a long span beam may reduce the tendency towards plastic lateral buckling sufficiently to allow the beam to display adequate rotation capacity at maximum moment, even when there is considerable distance between points of lateral support (Fig. 24).

5. Redistribution of moment due to the successive formation of plastic hinges actually occurs in indeterminate structures (Figs. 11 and 43) and thereby permits the realization of the computed load (Fig. 54). (Plastification of the cross section and redistribution of moment are the two factors that account for the increase in load capacity above "first yield.")

6. High shear stresses in a continuous beam may cause large deflections not predicted by the simple bending theory, but these additional deflections do not seriously affect ultimate load-carrying capacity (Fig. 11).

7. In a beam with a steep moment-gradient (beam with a concentrated load or in a corner connection), the strain-hardening which occurs immediately following plastic yield of the cross-section causes a rising rather than a horizontal load-deflection curve (Figs. 24, 36). This is an effect that is ignored by the simple plastic theory.

8. Subjecting a bending member to axial load reduces its ability to withstand bending moment (Fig. 31). Plastic theory affords an accurate means of predicting the effect; also, as predicted, the necessary hinges are developed (Fig. 30).

9. Welded connections for continuous frames can be fabricated to provide for the formation of plastic hinges and to develop the strength and rotation properties comparable to ordinary rolled sections (Fig. 35).

10. Although lateral support of a structure is necessary for it to develop its ultimate load, the magnitude of the

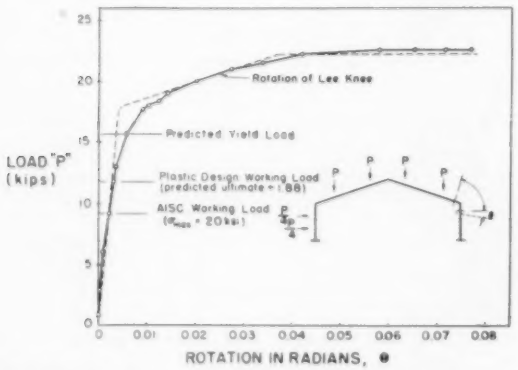
Rotation of Lee Knee
Predicted Yield Load
LOAD "P" (kips)
Plastic Design Working Load (predicted ultimate ÷ 1.88)
AISC Working Load
ROTATION IN RADIANS, θ

Fig. 44 Rotation at lee knee of gabled portal frame (T-9)

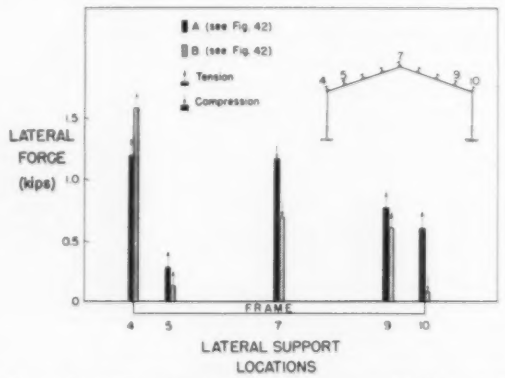

Fig. 45 Lateral support forces on gabled portal frame (T-9)

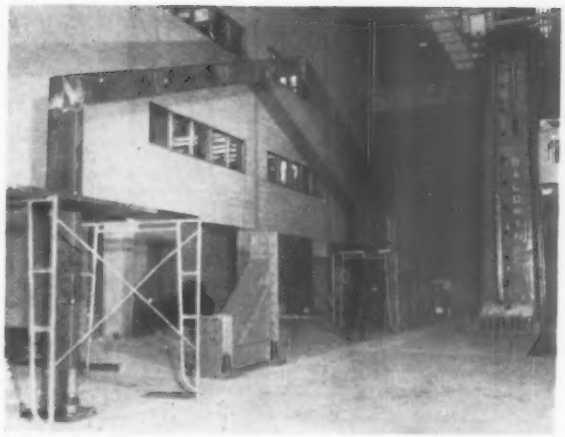

Fig. 46 A gabled portal frame of 40 ft span was fabricated of 12WF36 members and erected on the laboratory test floor.....

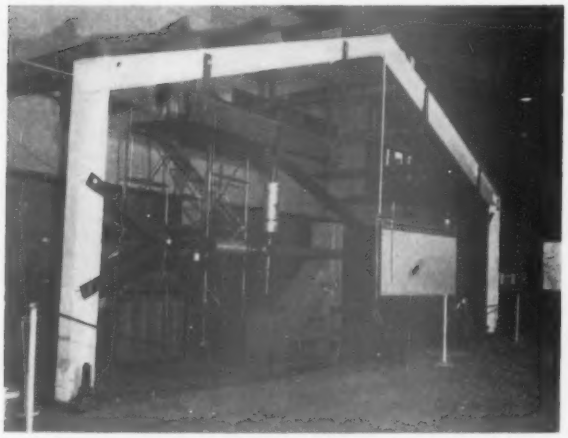

Fig. 47 .....after which loading equipment and instruments were added to the setup

necessary forces is quite small. The maximum value measured was less than 0.5% of the force required to compress the main member to yield point stress (Figs. 14, 37, 45).

11. Finally, the simple plastic theory is a reasonable basis for computing the ultimate load of structural members and frames (Fig. 54). Of all the tests, only one member was weaker than the computed value—and that by less than 2%.

Acknowledgments

This work was done at Lehigh University in Fritz Engineering Laboratory, of which William J. Eney is Director. The offering of the Summer Course was made possible by the American Institute of Steel Construction.

The willing help and cooperation of all the members of the Fritz Laboratory staff in preparing and conducting these tests is gratefully acknowledged. Special thanks go to Kenneth R. Harpel and his staff and to I. J. Taylor for their work in fabrication and setup of the specimens and instrumentation.

A. W. Huber, Y. Fujita, G. Haaijer, M. W. White, and B. C. Chapman provided most valuable assistance in taking charge of organizing and conducting individual tests. Narration during the tests was provided by F. W. Schutz, Jr., of Georgia Institute of Technology. He also assisted actively in the original planning of the tests while associated with the group at Lehigh University.

Appreciation is expressed to the secretaries who typed this report. D. L. McCullough calculated and plotted the results obtained from the tests. Valuable suggestions for the design of the test program were received from B. Thürlimann and R. L. Ketter.

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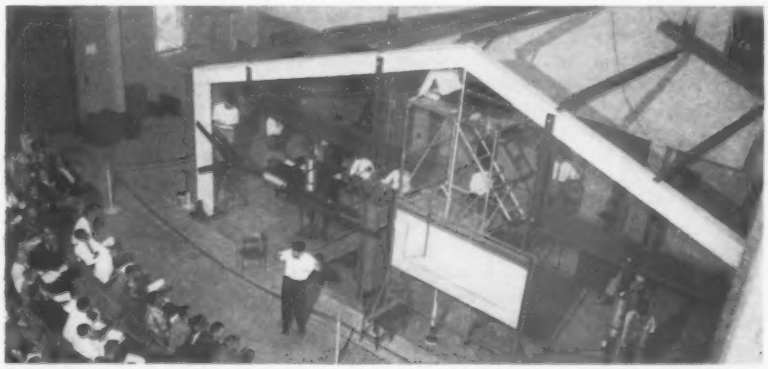

Fig. 48 A narrator described the application of loads to the structure as the test commenced

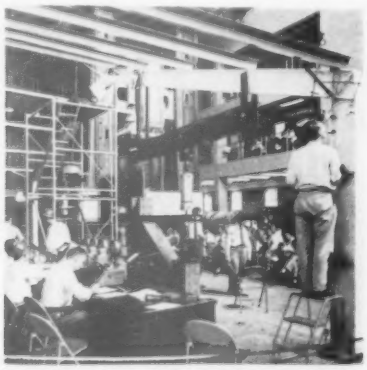

Fig. 49 Meanwhile, at the rear of the test setup a crew manned the loading pumps and measuring instruments

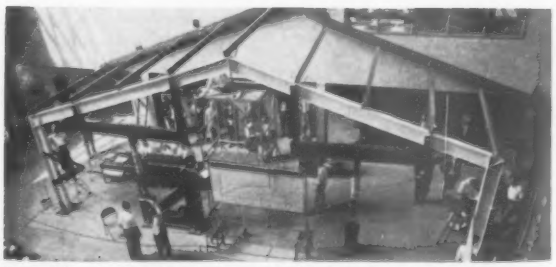

Fig. 50 As the load neared ultimate load, yielding could be noted at the knees, bases and center load points

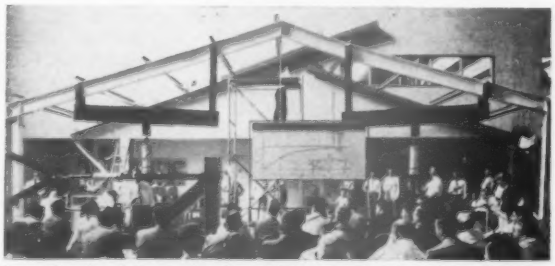

Fig. 51 At ultimate load, with the mechanism fully formed, deflections were visible but not excessive

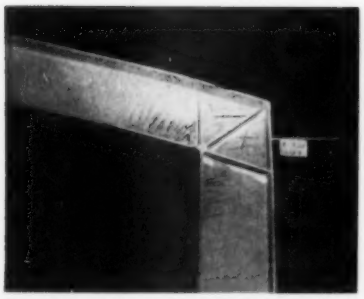

Fig. 52 After the conclusion of the test, the first plastic hinge in the leeward knee showed considerable yielding but no buckling

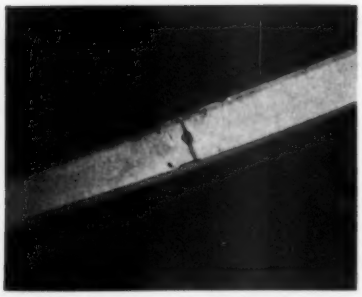

Fig. 53 Pronounced yielding was also visible at the last plastic hinge which formed at the windward center load point

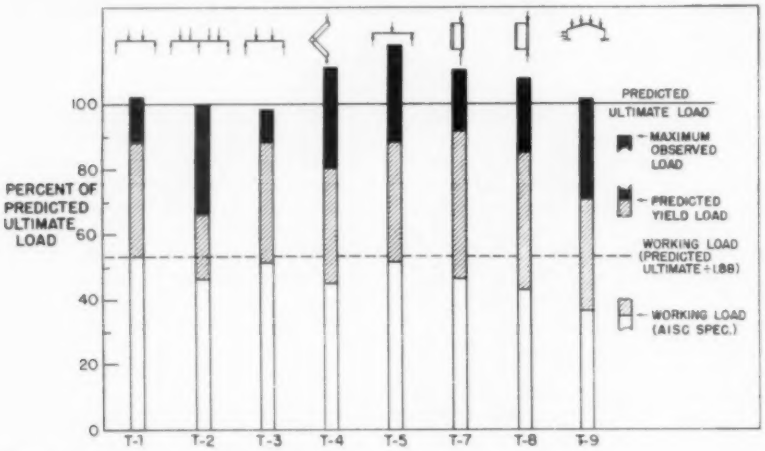

Fig. 54 Summary of test results

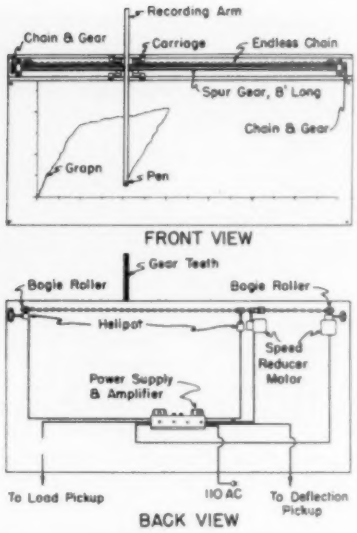

Fig. 55 Sketch of automatic plotting board

Part I—Test Results and Requirements for Connections, *The Welding Journal*, **30** (7), Research Suppl., 359-s (1951); Part II—Theoretical Analysis of Straight Knees, *Ibid*, **30** (8), Research Suppl, 397-s (1951); Part III—Discussion of Test Results and Conclusions, *Ibid*, **31** (11), Research Suppl., 543-s (1952).

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APPENDIX

Instruments Used in Tests

Automatic Plotting Board. The automatic plotting board is a device designed to plot a curve of load versus deflection electro-mechanically to large scale while a test is in progress. The board was designed and built by Ivan J. Taylor, Instruments Associate of Fritz Laboratory, especially for the Summer Course on Plastic Design.

A sketch of the plotting board is shown in Fig. 55. The experimental curve is drawn by a brush pen on a replaceable paper chart 8 by 4 ft in size. The pen is carried on a recording arm which is mounted to slide vertically on the carriage. The carriage has four wheels resting on tracks which allow it to be pulled horizontally across the panel. Horizontal motion is imparted to the carriage by an endless chain driven by a speed-reducer motor. The recording arm is driven vertically by the rotation of an 8-ft long spur gear coupled to a second speed-reducer motor.

The amount of motion of the driving motors is controlled by two bridge circuits, each containing two linear potentiometers, a voltage-controlled reversing switch, and a power supply. Each circuit is connected in such a way that if there is an unbalance between the two potentiometers, current will be directed to the motor, causing it to run either forward or backward. The motor is coupled by gear and chain drive to the second potentiometer as well as to its component of the recorder. This allows the motor to drive the second potentiometer until it balances the first, and thus cuts off the current to the motor.

The first or detecting potentiometer in each circuit is actuated either by a motion of the test specimen or a motion of a testing machine load indicating mechanism. This sets up the original circuit unbalance which causes the motor to drive the recording mechanism. Gear drive ratios are set so that a desired large motion on the chart is caused by whatever range of load or motion occurs on a given specimen.

Calibration of the plotting board is accomplished preliminary to actual testing by moving the detecting elements through several measured increments and marking the coordinate axes of the chart to correspond to these increments.

Dial Indicator. A dial indicator is a mechanical instrument used to measure small motions accurately by means of gear magnification. It is useful in combinations with level systems for many types of measurements. Dial Indicators and some of their applications are described in reference 5.

Rotation Indicator. Relative rotations between two cross sections in a bending member are measured by a rotation indicator. From these rotation measurements, the curvature of the member may be calculated. Rotation indicators are described in reference 4, and an example is shown in Fig. 17.

Dynamometer. A dynamometer is a load-measuring device. Dynamometers using SR-4 strain gages and strain indicators for measurement and indication are described in reference 3.

Twist Indicator. A twist indicator is used to measure the twist of a beam as an indication of lateral buckling. The twist indicator consists of a weighted pendulum which has as its pivot a circular-wound linear potentiometer which may be connected electrically to a remote reading dial indicator. The unit may be fastened to the compression flange of a beam. Any twist of the beam will change the setting of the potentiometer, causing a change in reading of the indicator. This is calibrated in terms of angles of rotation.

CORROSION RESISTANCE OF ZIRCALOY-2 BRAZEMENTS IN HIGH-TEMPERATURE WATER

Several alloys found to produce brazements which exhibit negligible corrosion when tested in 680° F pressurized water for periods up to and sometimes exceeding 1200 hours

BY J. B. McANDREW, H. SCHWARTZBART AND R. NECHELES

ABSTRACT. Brazements of simple geometry with Zircaloy-2 base metal were subjected to corrosion test in 680° F pressurized water for periods up to and sometimes exceeding 1200 hr. The filler metals used to prepare the corrosion test specimens included a large number of experimental alloys devised specifically for this purpose. Instances were observed in which specimens survived this test with little or no evidence of attack.

Further work is planned to determine whether some of these filler-metal alloys or variants of them may be applicable to nuclear-reactor fabrication.

Introduction

The corrosive attack of high-temperature, pressurized water on many metals and alloys is spectacularly rapid and destructive. Where the choice of materials is not particularly limited by other considerations, such corrosion can be avoided rather easily, but in the field of nuclear reactor design it is sometimes desirable to use materials of low thermal neutron capture cross section. Furthermore very little corrosion can be tolerated, and strength of the material at temperature may be quite important. Special zirconium base alloys have been developed to meet these requirements.[1] The fabrication of structures with such alloys would often be facilitated if brazing could be utilized as the joining method. A program of research was therefore formulated with the object of devising appropriate procedures and filler metals for this application.

Zirconium can be brazed to itself with only moderate difficulty, although the situation is by no means as simple as obtains with the more common metals and alloys. The brazing behavior and requirements are similar to those of titanium: gaseous contaminants should be rigorously excluded from the zirconium surface; heating cycles should be short; and heating beyond the flow temperature should be avoided. Some elements, such as copper, in the filler metal tend to cause severe erosion or inwashing of the base metal, and the formation of brittle intermetallic compounds may also be encountered.

The zirconium brazing problems become formidable, however, when the requirement for resistance to corrosion in high temperature water is introduced. Not only should the brazing alloy itself be corrosion resistant; all of the alloy compositions formed in the joint must exhibit that same property. Yet it is known that large additions of many elements to zirconium seriously reduce corrosion resistance of the resulting alloys. Furthermore, the many commercial brazing alloys and some experimental ones which had been tentatively investigated prior to the work reported here did not promise successful performance.

It is fortunate, at least, that the mechanism of corrosion in high temperature water is apparently such that galvanic effects are slight, and this aspect can largely be ignored.

Consideration of the problem as a whole led to the conclusion that the property of corrosion resistance must be achieved primarily, even though this might entail the sacrifice of desirable brazing characteristics or mechanical properties. Also, it was deemed advisable to gather corrosion data on brazements prepared with as wide a variety of filler metal compositions as possible in order to establish working hypotheses for the improvement of the better alloys. In short, the approach was empirical.

Factors considered in the selection of experimental alloys included melting ranges as indicated by available phase diagrams,[2] effects of component elements on the corrosion resistance of zirconium when alloyed with it, the undesirability of elements such as boron or cadmium because of nuclear considerations, and probable brazing characteristics with zirconium by analogy to common brazing alloys. The reasoning which led to the choice of each alloy will not be discussed here, but the matter was of sufficient complexity to constitute a considerable part of the research effort.

Materials

The base metal used for all brazements was Zircaloy-2, which contains in addition to zirconium, 1.5% Sn, 0.12% Fe, 0.10% Cr and 0.05% Ni, with a maximum nitrogen content of 60 ppm. This alloy, rather than pure Zr, was also used to make the zirconium base brazing alloys.

With the exception noted above, the metals used in alloy preparation were of the highest purity readily available. In the case of beryllium this was a grade with a nominal purity of only 96% ± 2%.

Experimental Procedures

Alloy Preparation

Two melting procedures were used for the preparation of alloys. The first was to induction heat in alundum crucibles under a bell jar with a helium atmosphere. The second method, used with the more reactive and refractory metals, was to arc melt with a tungsten electrode, a water-cooled copper crucible, and a helium atmosphere.

Brazing

All of the corrosion test specimens were made as single lap joints ½ to ¾ in. long x 1-in. wide. These were cut at the midpoint of the 1-in. dimension and one piece was used for metallographic examination, while the other was corrosion tested. Because it was thought that thin joints might be somewhat more corrosion resistant than those with large amounts of filler metal, no spacers were used for the original series

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of screening test specimens. This led to occasional difficulty where filler metals of high melting point were employed because there was doubt as to whether joining was obtained partly or entirely without benefit of filler metal. In most cases, however, the presence of filler metal in the joint could be clearly demonstrated metallographically.

The alloys which showed promising corrosion resistance were subsequently used to prepare specimens in which a joint spacing of 0.003 in. was maintained by means of a molybdenum shim.

Nearly all of the brazes were made by placing the filler metal outside of the joint and allowing it to flow in by capillary attraction. Most of the experimental alloys were brittle, so that preplacing could only have been done as powder; this would have been difficult without the use of a vehicle which would have introduced undesirable complicating variables.

All brazes were made in an inert atmosphere (usually helium, occasionally argon) without the use of flux. This was made possible by the fact that zirconium base alloys at brazing temperatures absorb surface oxidation films rapidly to leave a clean metal surface quite suitable for flow and bonding of the filler metal.

Initially, high purity tank helium was used without further treatment. Under these conditions, flow of some alloys was not satisfactory, and therefore the practice was adopted of passing the gas over titanium sponge heated to approximately 900° C. Later, a liquid nitrogen cold trap was also added to the system ahead of the titanium sponge furnace.

Heating of the specimen was done by induction. This was almost mandatory, since many alloys of unknown brazing characteristics were used, and control of the heating cycle was necessarily by visual observation. Also, this method allowed rapid heating and cooling.

Corrosion Testing

Corrosion tests were carried out in a standard type of stainless steel autoclave, equipped with temperature controller and pressure gage. Distilled water was used as the corrosive medium, and the air was carefully bled from the system at the start of each run. The specimens were immersed in the water, and were contained in a stainless steel basket. A temperature of 680° F was used in all tests, and each specimen was tested to complete failure (separation of the joined pieces) or to at least 1200 hr exposure time. The specimens were removed and examined at intervals varying from a few hours to several hundred.

The brazements which survived the 1200-hr test were broken apart when possible to permit examination of the brazed area. Those which could not be broken apart were sectioned and examined metallographically.

Fig. 1 Corrosion at edge of specimen brazed with Al–12% Si after 1413 hr exposure to 680° F water. X 150. (Reduced by one third upon reproduction)

Table 1—Corrosion Test Results for Specimens Brazed Without Spacing Shims, Exposed to 680° F Water

Filler-metal composition (nominal), wt/%	*Total exposure time, hr*	*Condition of specimen**
Ag–28 Cu	154 failed	.....
Ag–28 Cu	24 failed	.....
Ag–28 Cu	29.5 failed	.....
Ag–30 Cu–10 Si	29.5 failed	.....
Ag–30 Cu–10 Sn	1250	Filler metal was completely oxidized
Al–1 Ni	1318	Center of filler metal was completely oxidized although a corrosion resistant alloy layer was found adjacent to the base metal
Al (Hot dip coating)	163 failed	.....
Al–24 Pd	113 failed	.....
Al–12 Si	1413	Considerable attack along centerline of filler metal
Cu–7 P	86 failed	Was thick joint
Cu–7 P	1318	Virtually complete failure
Cu–15 Ag–5P–5 Sn	1201	Failure virtually complete
Cu–15 Ag–5P–10 Sn	1201	Failure virtually complete
Cu–20 Pd–3 In	1413	Virtually unattacked
Ni–7 P (Kanigen plate)	1367	Virtually unattacked
Ni–3.4 P	1313	75% of joint destroyed
Ni–30 Ge–13 Cr	104 failed	.....
Ni–20 Pd–10 Si	1367	Slight attack on filler metal
Ni–20 Cr–10 Si	1315	Extensive corrosion
Pd–6 Si	1310	Very extensive attack of Zircaloy adjacent to filler metal
Pd–10 Nb	1315	Very heavy attack of base metal
Pd–20 Sn	1413	Extensive base metal attack extending into filler metal
Zr–21 Cu	1311	80% of joint destroyed
Zr–17 Ni	1200	Heavy attack
Zr–15 Ni–10 Sn	1200	Extensive attack throughout joint
Zr–5 Be	1259	Unattacked
Zr–10 Fe–10 Sn	1200	50% of joint corroded
Zr–15 Fe–15 Mn	1200	20% of joint corroded
Au	23 failed	.....
Au–10 Co	1450	Virtually complete failure

* Specimens were removed from test after a minimum of 1200 hours and examined.

Experimental Results

The compositions of alloys used in the preliminary tests are shown in Table 1, together with the time after which failure was observed or the total number of hours after which the specimen was removed from test.

None of the aluminum base alloy brazements showed good corrosion resistance at 680° F. Although two specimens did not fail to the extent of actually separating, both were attacked. The Al–12% Si performed best, and would appear to offer some hope that a suitable aluminum base alloy might ultimately be developed. However, a very substantial improvement would be required, as may be realized by referring to Fig. 1, which is a photomicrograph of this specimen showing the extent of attack near one end of the Al–12% Si joint.

Of the copper base alloys tried, only one showed real promise. This was a nominal Cu–20% Pd–3% In alloy which actually analyzed Cu 76.95%, Pd 21.39%, In 1.74%. Figure 2 shows the attack at the edges of this specimen after 1413 hours exposure. A piece

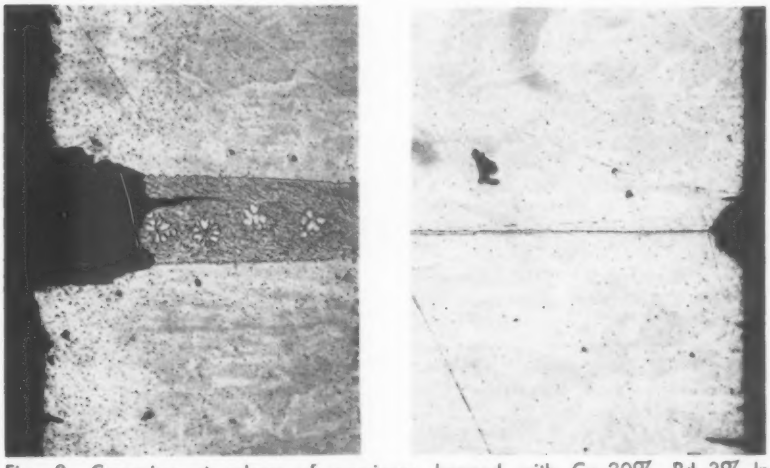

Fig. 2 Corrosion at edges of specimen brazed with Cu–20% Pd–3% In after 1413 hr exposure to 680° F water. X 150. (Reduced by one fourth upon reproduction)

of this alloy in sheet form was exposed for 3511 hours and appeared unaffected except for a light filming of the surface.

A nickel-base alloy containing approximately 6% P was chemically deposited and used as a filler metal. Virtually no attack was evident on this specimen after 1367 hr. Again, a specimen of this filler metal which had been melted and cast into a bar, and which analyzed 6.2% P was found to be unattacked during a corrosion test lasting 3379 hr. Two other alloys appeared promising in later tests, but not in this preliminary series. These were Ni–20% Pd-10% Si, and Ni–30% Ge–10% Cr, the latter being a proprietary alloy. The palladium base alloys not only exhibited corrosion in the braze proper, but also caused severe attack of the adjacent base metal. Figure 3 shows, for example, the appearance of a specimen brazed with Pd–6% Si after an exposure of 1310 hr.

None of the gold or silver-base alloys yielded corrosion resistant brazes. Of the zirconium-base alloys tried in this first series of tests, only the nominal Zr–5% Be alloy exhibited good corrosion resistance.

When the results of these preliminary tests had been evaluated, selected alloys were used to prepare specimens in which a minimum joint spacing of 0.003 in. was maintained by means of a shim. The alloys used and the corrosion test results obtained are shown in Table 2. Corrosion resistance was quite good for brazements prepared with alloys of the following nominal compositions: Cu–20% Pd–3% In, Zr–5% Be, Ni–20% Pd–10% Si, Ni–30% Ge–13% Cr, Ni–40% In, and Zr–10% Fe–10% Cr. The appearance of three of these specimens as broken apart after exposure may be seen in Figs. 4–6. The small dark areas visible on the surfaces of two of these are voids which did not fill during brazing, and should not be interpreted as corrosive attack.

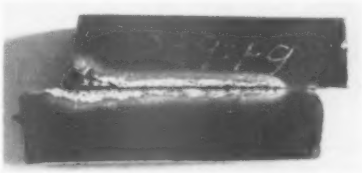

Fig. 3 Appearance of specimen brazed with Pd–6% Si after 1310 hr exposure to 680° F water. X 4. (Reduced by one half upon reproduction)

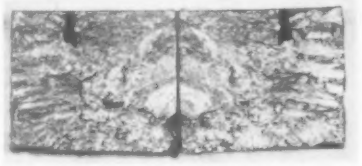

Fig. 4 Fracture surfaces of a specimen brazed with Cu–20% Pd–3% In exposed to 680° F water for 1311 hr and broken apart. X 2

Discussion

The results of the work reported here indicate that the achievement of satisfactory Zircaloy-2 to Zircaloy-2 brazements for use in high-temperature water may be anticipated with some optimism. However, it should be pointed out that the prediction of long time corrosion performance on the basis of accelerated tests is always difficult, and that this is especially the case when the corrosive medium is high-temperature water because sharp acceleration of attack has been known to occur after long incubation times. Furthermore,

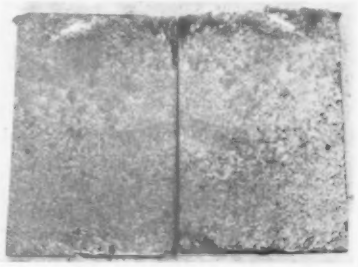

Fig. 5 Fracture surfaces of a specimen brazed with Ni–20% Pd–10% Si, exposed to 680° F water for 1300 hr and broken apart. X 1.5

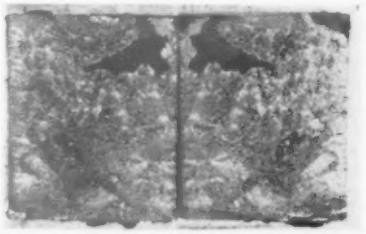

Fig. 6 Fracture surfaces of a specimen brazed with Zr–5% Be, exposed to 680° F water for 1200 hr and broken apart. X 1.5

Table 2—Corrosion Test Results for Specimens Brazed with 0.003-in. Spacing Shims, Exposed to 680° F Water

Filler metal composition (nominal), wt/%	*Total exposure time, hr*	*Condition of specimen*
Al–1 Ni	1200	Filler metal completely oxidized
Al–12 Si	364 failed	.....
Cu–7 P	610 failed	.....
Cu–3.5 P	830 failed	.....
Cu–15 Ag–5 Sn–5 P	128 failed	.....
Cu–15 Ag–10 Sn–5 P	585 failed	.....
Cu–20 Pd–3 In	1311	Unattacked
Ni–20 Pd–10 Si	1300	Unattacked
Ni–30 Ge–13 Cr	1419	Unattacked
Ni–40 In	1417	Little attack
Zr–5 Be	1200	Unattacked
Zr–10 Fe–10 Pd	1200	Complete filler metal attack
Zr–15 Fe–15 Mn	604 failed	.....
Zr–10 Fe–10 Cr	1235	Unattacked

in certain potential applications factors other than corrosion resistance may be important—for instance nuclear cross section, susceptibility to radiation damage or particular brazing characteristics. On the other hand, a foothold has been obtained from which to proceed in overcoming such difficulties if they are encountered.

The alloys which showed promising corrosion resistance were of surprisingly varied composition, and it would seem difficult to formulate a theory to account for the results obtained. In general, however, it may be said that silver-, gold- and palladium-base alloys were very poor, and it was noted that none of the aluminum-base filler metals tried was acceptable on the basis of the 1200-hr, 680° F criterion. In the latter case, the filler metal itself is probably susceptible, whereas in the case of silver and gold susceptibility probably results from pickup of zirconium during brazing. Palladium, on the other hand, apparently stimulates extensive corrosion of the base metal itself, far beyond the braze region. It is not known whether this is attributable to diffusion of palladium, or perhaps interstitial solutes from the palladium, into the base metal. Thus it is likely that a number of complex factors would have to be considered and evaluated in order to account theoretically for the behavior of the various corrosion specimens.

Further work is planned with emphasis being placed on the alloys Zr–5% Be, Cu–20% Pd–3% In, Ni–20% Pd–10% Si, Ni–30% Ge–13% Cr, and Ni–6% P. Compressive shear tests of brazements prepared with the first four alloys listed have been performed, and these showed useful strengths ranging from 17,000 to over 50,000 psi. The alloy which is presently judged to be best on the basis of melting range, flow characteristics, strength, freedom from erosion of the base metal and corrosion resistance is Zr–5% Be.

Summary

Some thirty different alloys were used to braze Zircaloy-2 to Zircaloy-2 specimens which were then corrosion tested at 680° F for times up to 1200 hr or more. Several alloys produced brazements which exhibited negligible corrosion in this test. Further work is to be done with the object of determining whether these or similar alloys may be usable in nuclear reactor fabrication.

Acknowledgments

The work reported here was performed for Bettis Plant which is operated by the Westinghouse Electric Corp. for the Atomic Energy Commission, and permission to publish this paper is gratefully acknowledged. Thanks are due to Dr. D. E. Thomas and others of Bettis Plant for counsel and advice in planning the work, and to the many colleagues at the Armour Research Foundation who contributed to experimental phases of the work. The Ni–Ge–Cr alloy was supplied by the General Electric Co., Aircraft Nuclear Propulsion Department.

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WELDING HEAVY SECTIONS BY THE RUSSIAN ELECTRO-SLAG PROCESS

BY W. ANDERS

The Paton Institute of Electric Welding in Kiev, Russia, developed the arcless electro-slag welding process, which has been used in production welding since 1951. This article is based on a book[1] describing the process and on experience in the Central Welding Institute of East Germany with the Russian electro-slag welder A372. Prof. B. E. Paton and Dr. Seybo of the Paton Institute discussed the process in detail with the author.

Description Process. Unlike arc welding with open or submerged arc, the heat in the electro-slag process is derived from the electrical resistance of the slag. Only at the start of welding is an arc required to melt the slag. As soon as sufficient flux is melted, which is prevented from flowing out of the joint by water-cooled molds, the arc is extinguished and all heat is derived from current flowing through the slag, Fig. 1. This diagram shows a weld being made in 4-in. steel plate, the edges being separated $1^3/_{16}$ in. The water-cooled sliding copper molds on both sides of the plates confine the slag and the weld metal beneath it. The depth of the slag governs the amount of current flowing into the plate and thus the penetration. The current should be adjusted to yield a trough-shaped weld puddle.

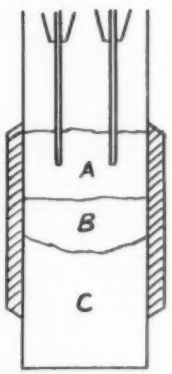

Fig. 1 Sketch of the electro-slag welding process. The distance from the surface of the slag to the end of the wire guide tube is $2^3/_8$ to $3^1/_8$ in. for steel plate 4 in. thick. The shaded plate on both sides of the weld is the sliding, water-cooled copper mold

A, molten slag; B, molten weld puddle and C, solid weld metal

The thermal conditions in electro-slag welding are compared with arc welding in Table 1. The joint is in the vertical position and the weld metal follows the electrodes as they move slowly upward. Pronounced dendritic structure is observed. If the weld puddle is too shallow, the dendrites are

(*Continued on page 306-s*)

Abstract by Gerard E. Claussen of "Das Lichtbogenlose Schweissen Dicker und Grosser Kompakter Querschnitte mit der Elektro-Schlacke-Schweissung," published in *Schweissen und Schneiden*, **9**, 12–24 (1957).

Dr. Claussen is associated with the Development Laboratories, Linde Company, Newark, N. J.

[1] Paton, B. E., and co-workers, "Electro-Slag-Welding," Mashges, Kiev (1956).

DUCTILITY OF TUNGSTEN-ARC WELDS IN MOLYBDENUM

Good bend ductility reported for all welds made in a dry box. Satisfactory results also obtained with inert-gas shielding cup and with leading-trailing shield unit

BY N. E. WEARE, R. E. MONROE AND D. C. MARTIN

ABSTRACT. The objectives of this study were: (1) to study some of the variables encountered in welding molybdenum, (2) to study the possibility of welding molybdenum outside of a dry box, and (3) to determine if welds of consistent ductility could be made in different lots of arc-cast carbon-deoxidized molybdenum. Good bend ductility at 25° and 75° C was found for welds made using the best procedures established for dry-box and conventional welding.

Welds were made in the dry box to study the effects of cleaning methods, initial sheet microstructure, and two levels of atmosphere purity. Only atmosphere purity had a significant effect on weld ductility. Five methods of shielding welds made in air were studied and the effects of type of inert gas used, gas flow, and nozzle size were determined with standard inert-gas shielding cups. A standard shielding cup and a leading-trailing shield unit have produced the best welds made in air to date. Other promising shielding methods are still being studied. The extent of tungsten contamination of molybdenum welds during tungsten-arc welding also were studied. About 3 w/o tungsten in a molybdenum weld lowered weldment ductility. Weld porosity was associated with oxides or gas trapped along sheet edges.

Welds were made in six heats of arc-cast molybdenum with about the same carbon content both in air and in the dry box for a consistency run. A significant difference in bend ductility was found between welds made in the different heats.

Introduction

Molybdenum has many properties which would make it a useful structural material for many high-temperature uses. The major drawback to the use of molybdenum structures in nonoxidizing environments is low weld bend ductility between room temperature and about 400° F. Research programs during the past several years have been conducted to overcome the weld ductility problem. Important gains were made with the discovery that fairly ductile welds could be made in recent commercial molybdenum in high-purity dry-box atmospheres.[1] Most significantly, these welds were made by the widely used and versatile tungsten-arc welding process.

Since earlier work[1] was devoted to comparing a large number of molybdenum alloys, standard procedures were followed in producing test weldments. These procedures were believed to be satisfactory, but alternate methods were available in many cases. Tests to establish optimum procedures were made by studying cleaning methods, preweld sheet structure, and atmosphere purity. Weldments made in a dry box were bend tested using single point loading at a high strain rate to determine the effects of these variations.

While many welding jobs could be done in a dry box, final assembly of components and welding of large pieces would have to be made in air. A preliminary study was made of some methods of shielding molybdenum for welding outside the dry box. Five shielding methods were studied: (1) a standard ceramic inert-gas shielding cup, (2) a leading and trailing shield unit, (3) a leading shield, (4) a plastic bag to shroud the weld area from the air, and (5) a dragging shield.

In all cases, a helium gas backing was used to protect the back of the weld. A study was also made of the effects of gas flow, nozzle size and type of gas used on weld ductility. Small amounts of tungsten were seen dropping from the tip of the electrode while welding in air. Attempts were made to determine the extent of tungsten contamination in tungsten-arc welds in molybdenum.

Good bend ductility was obtained for all welds made in the dry box. Of the cleaning methods studied, etching in a chromic acid solution was chosen as the best and most practical method to clean molybdenum for welding. Welds made in a high-purity atmosphere were slightly more ductile than welds made in a low-purity atmosphere. Recrystallization of sheet prior to welding had no effect on weld ductility. Under the best condition, weldments had an average bend angle of 64° before fracture when bent at 1 ipm at room temperature.

Of the shielding methods tried in air, the inert-gas shielding cup and the leading-trailing shield unit produced welds with good ductility, but not equal to dry-box welds. From the studies made using the ceramic cup, it was found that a helium flow of 40 cfh through a $^5/_8$-in. diam nozzle produced the most ductile welds. Welds made in the plastic bag were very porous and showed no improvement in ductility. Results of tests made using a leading shield and a dragging shield were inconclusive and further work will be done using these shields. Attempts to determine the extent of tungsten contamination during normal welding were unsuccessful. However, bend tests made on a molybdenum weld with tungsten deliberately added showed a loss in room temperature ductility.

Using the results found for welds made in air and in the dry box, a consistency run was made in six different lots of molybdenum. The results of this consistency run showed a significant difference in weldment bend ductility between different heats of arc-cast molybdenum of about the same carbon content. There was a much more significant difference between welds made in air than between welds made in the dry box.

This paper is divided into sections describing materials, experimental procedures, experimental results, and the consistency run. Under experimental results discussions of welds made in the

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Presented at 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8-12.

Table 1—Ductility of Sheet Used for Welding Studies

(Sheet Stress Relieved 1 hr at 1800° F in H_2)

Sheet no.	Carbon content, w/o	Permanent bend angle, degrees at[a] 25° C	75° C
C12	0.046	90NF[b], 90NF, 90NF, 90NF	Not tested
C20	0.017	8, 40, 70, 90NF, 90NF, 60	90NF, 90NF, 90NF, 90NF, 90NF, 90NF
C21	0.020	90NF, 90NF, 90NF, 90NF, 90NF, 90NF	Not tested

(a) Average values for each set of samples underlined.
(b) NF = no fracture.

dry box, welds made in air, porosity, and tungsten contamination are found. The section on the consistency run is divided into description of materials, procedures and results.

Material

A single heat (C20) of $^1/_{16}$-in. thick carbon-deoxidized arc-cast molybdenum containing 0.017 w/o carbon was used for most welding studies. Results of transverse bend tests (Table 1) on Sheet C20 showed a lower ductility than for sheet tested in previous studies. For comparison, data are included in Table 1 for bend tests at room temperature on commercial sheet used in previous work. Since the room-temperature ductility was low for the sheet, tests were made at a temperature above 25° C to see if consistent 90° bending* without fracture could be obtained. At 75° C (the first temperature tried), consistent 90° bending was obtained without fracture.

Metallographic examination of this sheet showed very coarse grains elongated in the direction of rolling. The surface of the sheet was cold worked more severely due to the chilling effect of the rolls. There was evidence of laminations between the fibered surface and the coarse-grained interior of the sheet. Massive carbides also were visible in the sheet. Figures 1 and 2 show the microstructure of the sheet. Examination of this sheet when it was rolled to about 0.080 in. thick showed a completely recrystallized grain structure. Not enough cold work was put into the sheet between 0.080 and 0.062 in. to produce a ductile, fibered structure. Sheets C12 (used in previous work) and C21 were fibered and showed much better bend ductility. Sheet C21 was chosen to study the effect of recrystallization of the sheet on weld ductility.

* Limit of test equipment.

Experimental Procedures

In previous studies of titanium-neutralized and carbon-deoxidized arc-cast molybdenum, special equipment and procedures were developed to minimize weld contamination. This study did not include work on the effects of prewelding and welding variables on the weldment ductility. These procedures were modified in this program to study the effects of sheet cleaning procedures, sheet microstructure and atmosphere purity on the ductility of weldments made in a dry box. Since welding in a dry box would not always be practical, preliminary work was also done to develop procedures for the inert-gas-shielded tungsten-arc welding of molybdenum in air. Variables studied were shielding devices, shielding gas and gas flows. Attempts to determine the cause of porosity, the extent and effect of tungsten contamination of inert-gas-shielded tungsten-arc welds were made also. The following section describes the equipment used in welding and the procedures used before, during and after welding.

Equipment

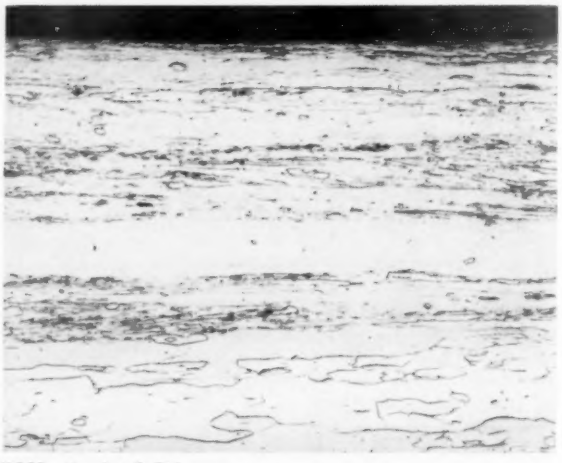
The welding dry box and auxiliary equipment used for this study were described previously.[1] This dry box is purged to a vacuum of 0.1 micron of mercury. By rapidly admitting gas from a high-pressure cylinder and then gettering the atmosphere by welding on titanium or zirconium, a high-purity welding atmosphere can be obtained. A constant-voltage welding head, a 400-amp d-c rectifier, and a moving carriage were used for welds made in the dry box and in air.

Shielding devices used for the study of weldments made in air were: (1) a standard ceramic inert-gas-shielded welding cup, (2) a leading and trailing shield unit, (3) a leading shield, (4) a plastic bag to shroud the welding area, and (5) a dragging shield. The leading-trailing shield unit, the leading shield and the dragging shield were used in conjunction with an inert-gas-shielding cup. In all cases, a helium backing was used.

The ceramic cups (Fig. 3*a*) used had $^3/_8$-, $^1/_2$-, and $^5/_8$-in. diam gas orifices. The gas surrounded the tungsten electrode and the arc, and protected the molten weld pool. The trailing shield unit (Fig. 3*b*) consisted of a leading shield, a ceramic cup and a trailing

X 250 Murakami's Etch

Fig. 1 Longitudinal section of sheet C20



X 250 Murakami's Etch

Fig. 2 Transverse section of sheet C20 showing the fibered surface

shield. This shield unit fit on the ceramic cup and gas from it afforded protection from oxidation to the area ahead of the arc, the molten weld pool and the completed weld. A gas baffle, consisting of a porous stainless steel sheet, was brazed into the shield to give a more even gas flow. A leading shield (Fig. 3*c*) was designed to protect the unwelded portion of the joint ahead of the arc from oxidation. This shield was designed for use with the $^5/_8$-in. ceramic inert-gas-shielding cup. A porous stainless steel gas baffle was brazed into the shield to produce a uniform gas flow.

To shroud the entire weld area from the air, a polyethylene bag clamped between the electrode holder and a special jig was made to determine if weld ductility could be improved using this method. No cup was used in connection with the plastic bag. Gas was admitted to the bag through a backing and through the welding head, and a positive pressure was maintained throughout purging and welding operations by adjusting gas outlet valves in the bottom of the jig.

A dragging shield (Fig. 3*d*) was designed to fit directly on the molybdenum sheet being welded and act somewhat as a welding chamber to shield the weld from the air. This shield was made to fit the contour of the welding jig leaving a small gap to allow gas to escape during welding. Plexiglas windows were placed at each end of the shield to facilitate alignment and to allow observation of the weld being made.

In all cases, a gas backing was used to provide protection for the back of the weld. This backing consisted of two pieces of $^3/_{16}$ by $^1/_2$-in. copper bar with a $^1/_8$-in. spacer for the bottom. A strip of porous stainless steel was forced into the $^1/_8$-in. gap for the entire length. Helium was admitted to the backing at each end.

Prewelding Treatment

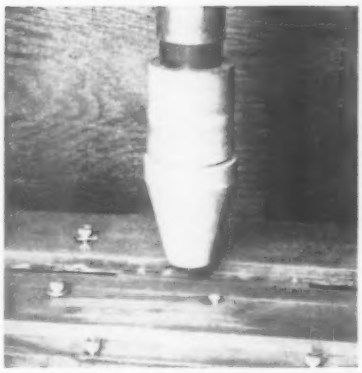
The cleaning of joint surfaces before welding is particularly important in producing ductile fusion weldments in molybdenum. Slight oxide films and, possibly, high impurity levels at the sheet surface can cause embrittlement of molybdenum weldments. A study was made using the following four cleaning methods:

1. The surface was cleaned with a fine emery cloth and degreased in acetone.

2. The sheet was etched for 30 sec in a chromic acid etch (95 v/o H_2SO_4, 4.5 v/o HNO_3, 0.5 v/o HF, and 18.8 g per liter Cr_2O_3).

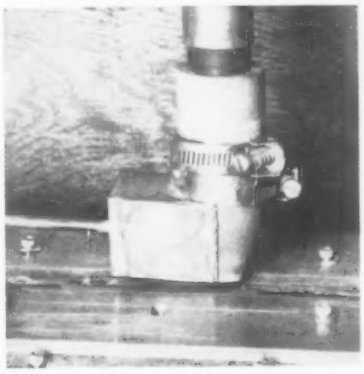
3. The sheet was etched electrolytically 30 sec in Coon's electrolyte (150 ml methyl alcohol absolute, 50 ml HCl, and 20 ml H_2SO_4).

4. The sheet was etched electrolytically in a solution of 50 v/o H_2O and 50 v/o HCl for 30 sec.

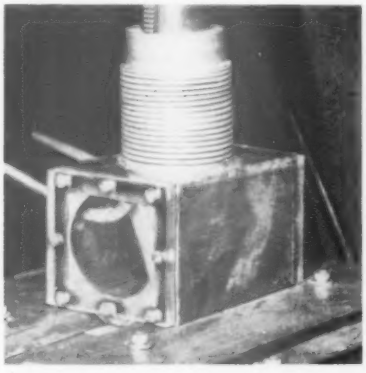


a. Ceramic inert-gas shielding cup

b. Leading-trailing shield unit



c



d

Fig. 3 Shields used in the study of molybdenum weldments made outside the dry box

In all cases the work moves beneath the arc from left to right

All cleaning methods were followed by a hot-water rinse; then, by an acetone rinse. The chromic acid etch was used for all welds made in air and all remaining welds made in the chamber to study variables other than cleaning procedures. Heavy oxide on Sheet C20 was removed in a molten martempering salt bath. All other sheet was received with the heavy oxide removed.

Other sheet was prepared to study the effects of prior sheet microstructure on the ductility of weldments. Since the sheet (C20) used for most studies was coarse grained, specimens were cut from a fibered sheet (C21) for welding studies. One specimen was welded in the as-rolled condition, and the other was recrystallized at 2000° F for 2 hr in flowing tank hydrogen prior to welding.

Welding

The normal welding procedures used in the dry box were the following: (1) specimens were loaded after cleaning, (2) the dry box was evacuated to 0.1 micron of mercury, (3) gas was admitted directly from a high-pressure cylinder, and (4) a getter arc was run on titanium for several minutes before welding each molybdenum sample. To obtain a low-purity atmosphere, the chamber was evacuated to a vacuum of 100 microns of mercury, and gas was admitted. The atmosphere was not gettered. Welding conditions for welds made in the dry box are given in Table 2. Most welds made in the dry box were bead-on-plate welds.

Square-butt welds were made in air using helium or argon as a shielding gas. Before welding, the ceramic cups and the special shielding units were dried to drive off any moisture they had picked up. Helium was allowed to flow through the equipment to dry it out and welds were made on scrap to assist in drying the electrode collet and gas backup. In using the plastic-bag shield, helium was allowed to flow through the backing and through the welding head for about 5 min to purge the bag of air. Helium remained flowing while the weld was being made. Two gas outlets in the bottom of the jig were adjusted to maintain a positive pressure in the bag. No shielding cup was used around the electrode. The dragging shield was purged for two minutes before welding.

Welding specimens were held on a copper jig by two hold-down plates and

Table 2—Welding Conditions for Tungsten-Arc Welds Made in the Dry Box Grade A Helium Atmosphere, Straight Polarity, Direct-Current, Voltage Sensitivity Control Normal, ¼-in. Thoriated-Tungsten Electrode

Specimen no.	*Cleaning method*	*Ultimate vacuum, micron of Hg*	*Prior heat treatment*	*Welding current, amp*	*Arc voltage, volts*	*Weld speed, ipm*	*Remarks*
C20-1	Emery paper	0.1	None	222	20	12	100% penetration
C20-2	Chromic acid etch	0.1	None	224	20	12	100% penetration
C20-3	Coon's electrolytic etch	0.1	None	224	20	12	100% penetration
C20-4	H_2O-HCl electrolytic etch	0.1	None	224	20	12	100% penetration
C20-5	Chromic acid etch	100.0	None	212	24	12	100% penetration but not so much as above
C21-1	Chromic acid etch	0.2	None	220[a]	20[a]	12	100% penetration
C21-2	Chromic acid etch	0.2	Recrystallized	220[a]	20[a]	12	100% penetration, electrode stuck at beginning of weld

(a) Meters were not used, value estimated from previous welds.

moved under the arc on a traveling carriage. Starting and finishing tabs were used for all butt welds. All welds, except the one made using argon, were made using the constant-voltage welding head. Since the head could not be controlled properly in argon using d-c straight polarity, the welding head was used as a fixed torch and the arc was started by a high-frequency spark. A helium gas backing was used for all welds made in air. No filler metal was used for either welds made in air or those made in the dry box. Table 3 gives the data for welds made in air. Completed welds were stress relieved 1 hr at 1800° F in flowing hydrogen.

Testing

Coarse-grained molybdenum structures exhibit a transition from ductile to brittle behavior around room temperature. In previous studies, tests over a temperature range have been used to determine transition temperatures for comparing materials. However, since in practice ductility below room temperature is at present unimportant, tests during this work were made at 25° and 75° C only. By testing a number of small samples cut from each weld at each temperature, an average measure of ductility was obtained.

Bend tests were made transverse to the direction of rolling and welding. Under this type of loading, molybdenum has lower ductility than would be found in tension or longitudinal bending. Specimens were bent until fracture occurred or to a maximum angle of 90°.* The permanent bend angle after fracture was measured to indicate the degree of plastic deformation. The conditions used in bend testing are listed below:

Type of test = simple single-point loaded bend test

* Limit of test equipment.

Table 3—Welding Conditions for Inert-Gas-Shielded Molybdenum Welds Made in Air, Straight Polarity, Direct Current, 1/8-in. Thoriated-Tungsten Electrode, Weld Speed 12 ipm

Weld no.	*Shield used*	*Gas Flow, cfh[a]*			*Electrode protrusion[b], in.*	*Welding current, amp*	*Arc volts*	*Remarks*
		Cup	*Backing*	*Trailing shield*				
C20-A	3/8-in. cup	40	30	..	1/8	222	20	Face of weld oxidized, longitudinal and transverse cracks, back of weld bright.
C20-B	3/8-in. cup	30	30	..	5/32	208	16	Face of weld oxidized, some porosity, back of weld bright.
C20-C	3/8-in. cup	40	30	..	1/8	212	15	Face of weld oxidized, slight porosity, back of weld bright.
C20-D	3/8-in. cup	40	30	..	1/8	214	15	Face of weld oxidized, slight porosity, back of weld bright.
C20-E	3/8-in. cup	80	30	..	1/8	224	22	Slightly oxidized surface, slight porosity, back of weld bright.
C20-F	3/8-in. cup	15 (argon)	30 (helium)	..	1/8	268	12.5	Face of weld oxidized, poor weld shape, large amount of porosity, back of weld bright.
C20-G	Trailing shield	40	30	30	1/8	220	15	Face of weld bright, slight porosity, back of weld bright.
C20-H	Plastic bag	40[c]	30	..	..	206	17	Face of weld bright, gross porosity, cracks, hole burned in bag at start of weld, back of weld bright.
C20-I	Plastic bag	40[c]	15	..	..	210	17	Face of weld bright, gross porosity, back of weld bright.
C20-J[d]	1/2-in. cup	40	20	..	1/4	210	17	Face of weld oxidized, large amount of porosity, tungsten melted into weld, back of weld bright.

(a) Grade A helium used except where noted for C20-F.
(b) Electrode protrusion is the distance the electrode protrudes below the shielding device.
(c) No shielding cup used, gas flows around electrode.
(d) This weld was made using the circular jig made for the plastic bag. Greater electrode protrusion was required because of steep bevel on hold-down plates.

Table 4—Effects of Cleaning Procedures on the Ductility of Carbon-Deoxidized Molybdenum Weldments

Weld no.	*Cleaning procedure*	*Permanent bend angles at fracture, degrees at*[a] *25° C*	*75° C*
C20-1	Emery paper	4, 6, 16, 20, 25, 30, 30, 40, 50, 50, **27**	30, 40, 40, 50, 60, 70, 70, 80, 90, 90NF[b], **62**
C20-2	Chromic-acid solution	12, 35, 40, 40, 40, 40, 40, 50, 60, 60, **42**	10, 30, 55, 60, 70, 70, 80, 90, 90, 90, **64**
C20-3	Coon's electrolytic etch	4, 10, 10, 12, 20, 20, 30, 30, 40, 40, 50, **24**	50, 50, 60, 60, 80, 80, 90, 90, 90NF, 90NF, 90NF, **78**
C20-4	HCl-H_2O electrolytic etch	4, 6, 12, 14, 30, 50, 50, 50, 70, **32**	18, 35, 50, 60, 60, 65, 70, 90, 90, 90NF, **63**

(a) Average values for each set of samples shown in bold type.
(b) NF = no fracture.

Test temperature = 25° and 75° C
Deflection rate = 1 ipm
Strain rate = 0.016 in. per in. per sec at start of bend
Specimen dimensions = $^1/_{16}$ x $^1/_8$ x $^3/_4$ in. minimum length

Tests at 25° C were used to study the room-temperature ductility of the weldments. The sheet used for most of the work was not completely ductile at room temperature. In order to test weldments at a temperature above the sheet's brittle-ductile transition range, tests were made also at 75° C which supplemented the data obtained at 25° C.

Since the previous study had shown an improvement in bend-test ductility for weld specimens with the tension face ground and rough polished, all specimens were tested with the weld surface ground. The first few welds tested did not have the surfaces ground completely flat, leaving depressions at the weld fusion lines. Bend specimens from these welds had a tendency to fracture through this reduced section at low permanent bend angles. It was found that better ductility was obtained when the welds were ground flush on the surface. This also eliminated many of the fusion-line fractures. Surface grinding was accomplished with a 150-mesh belt and polishing with a fine emery wheel or a 400-mesh belt to give a smooth surface for testing.

Experimental Results

Room-temperature ductility was obtained from welds made both in the dry box and in air. Cleaning in chromic-acid solution and welding in a high purity dry-box welding atmosphere produced the most ductile welds. Recrystallizing the sheet prior to welding had no effect on weld ductility. Welds were made in air with ductility approaching the ductility of welds made in the dry box.

Studies Made in the Dry Box

Weldments were made in the dry box to determine the effect of cleaning procedure, prior sheet microstructure, and welding-atmosphere purity.

Cleaning Procedures. Four cleaning procedures were used to determine the best method of cleaning molybdenum before welding. These procedures were described earlier under experimental procedures. Weld-bend test data from this study are shown in Table 4. At room temperature, the weld made in the sheet etched in the chromic-acid solution exhibited the best ductility, the other methods producing welds of slightly lower ductility and about equal to each other. However, at 75° C the weld made in the specimen etched electrolytically in Coon's electrolyte exhibited superior ductility to the other methods, the other three having equivalent ductility.

From the results of these studies, it was concluded that no cleaning method was far superior to the others studied. The chromic-acid solution (95 v/o H_2SO_4, 4.5 v/o HNO_3, 0.5 v/o HF, and 18.8 g/liter Cr_2O_3) was chosen for future work because it is easiest to use, and it would be the best method of those studied for cleaning complicated parts for welding. One major drawback to many electrolytic and acid-cleaning methods is the severe grain-boundary attack. The chromic-acid solution does not appear to attack molybdenum grain boundaries severely.

Sheet Microstructure. A study was made of the effect of recrystallizing molybdenum sheet before welding. It was thought that laminations present in fibered molybdenum sheet might give rise to porosity or loss of weld ductility. In a previous study made on titanium - neutralized - molybdenum alloys, it was found that the general effect of rolling at the low temperature which produced serious laminations in the sheet was to lower weld ductility and increase scatter within the transition range. By recrystallizing fibered sheet, it was thought that any effect of laminations would be eliminated.

Since the molybdenum sheet used for other studies reported in this paper was coarse grained, weld specimens were cut from a fibered sheet (C21). One specimen was welded in the as-rolled condition, and the other was recrystallized at 2000° F for 2 hr in flowing hydrogen before welding. Results of the bend tests are shown in Table 5. As can be seen from these data, there was no improvement in weldment bend ductility for the recrystallized molybdenum. As can be seen, however, the ductility of these welds, both the fibered and recrystallized sheet, was slightly improved over that in Sheet C20.

Welding - Atmosphere Purity. All molybdenum welding done previously had been done in a high-purity welding atmosphere. If welds could be made in a lower-purity atmosphere, time and cost could be lowered. By purging the dry box to a vacuum of 100 microns of mercury, the use of a diffusion pump would be eliminated and pumping time would be less. By testing a weld made in a low-purity atmosphere, the possible effects of a slightly contaminated atmosphere were checked. The methods of obtaining high- and low-purity atmospheres were discussed in an earlier section.

Table 6 lists the data for the welds made in high- and low-purity helium atmospheres. The welds made in high-purity helium had better room-temperature ductility, but ductility at 75° C was comparable. It was concluded that welds with some ductility can be obtained in lower purity atmospheres, but higher-purity welding at-

Table 5—Effect of Sheet Microstructure on Ductility of Carbon-Deoxidized Molybdenum Weldments

Weld no.	*Sheet structure prior to welding*	*Permanent bend angle at fracture, degrees at*[a] *25° C*	*75° C*
C21-1	Fibered	4, 20, 25, 30, 30, 40, 50, 90, **36**	40, 50, 60, 90, 90NF[b], 90NF, 90NF, 90NF, **75**
C21-2	Recrystallized	4, 14, 18, 35, 35, 60, 70, 80, **40**	50, 60, 60, 80, 90NF, 90NF, 90NF, 90NF, **76**

(a) Average values for each set of samples shown in bold type.
(b) NF = no fracture

Table 6—Effect of Welding-Atmosphere Purity on the Ductility of Carbon-Deoxidized Molybdenum Welds

Weld no.	Ultimate vacuum, micron of Hg	Permanent bend angle at fracture, degrees at[a] 25° C	75° C
C20-2	0.1	12, 35, 40, 40, 40, 40, 40, 50, 60, 60, **42**	10, 30, 55, 60, 70, 70, 80, 90, 90, 90, **64**
C20-5	100.0	4, 8, 25, 30, 30, 30, 35, 40, 40, 40, **28**	16, 40, 40, 50, 50, 60, 80, 90, 90, **57**

(a) Average values for each set of samples shown in bold type.

mospheres should be used to insure the best room-temperature ductility.

Studies Made in Air

Since it would not always be practical to weld molybdenum in a dry box, a preliminary study was made to determine if ductile molybdenum welds could be made outside the dry box. The shielding methods tried and welding data were previously given in Table 3. Of the shielding devices studied, a ceramic cup and trailing-shield unit produced welds with the best ductility. Insufficient data are available to determine the effectiveness of the leading and dragging shields, although they appeared promising. Bend-test data for the welds made in air are given in Table 7.

Inert-Gas-Shielding Cup. The inert-gas-shielding cup was tried initially to be used as a basis for comparison of the effectiveness of the other shielding devices. This type of shield is easier to use and allows the best visibility of the arc. Ductility of initial welds made using a ceramic inert-gas-shielding cup was surprisingly good at room temperature. An investigation was then set up to study the effects of: (1) cup size, (2) helium flow rate, and (3) argon versus helium as a shielding gas. Cups of $^3/_8$- and $^5/_8$-in. diam gas orifice were used; helium flows of 30, 40 and 80 cfh were tried; and one weld was made using 15 cfh argon. All welds were made using a helium-gas backing of 30 cfh. One other weld of this type (C20-J) will be discussed under a later section on welds made in the plastic bag.

Butt welds were made using $^3/_8$- and $^5/_8$-in. ceramic inert-gas-shielding cups and 40 cfh helium flow to study the effect of nozzle size. The weld made using the $^3/_8$-in. nozzle (C20-A) was badly cracked for about half its length. Bend tests of the sound portions of this weld indicated a much lower ductility than the weld made using the $^5/_8$-in nozzle and the same helium flow (C20-C). Work done by other investigators has shown that lower helium flows must be used with the smaller diameter cup.[2] Probably, at 40 cfh helium flow the gas envelope was turbulent when using the $^3/_8$-in. cup and a lower flow rate would produce a more ductile weld. The $^5/_8$-in. nozzle, however, appeared to give better protection in the hot zone immediately ahead of the molten weld pool and prevented oxidation of this area before welding.

A study of the effect of gas flow was made using a $^5/_8$-in. ceramic cup and helium flows of 30 (C20-B), 40 (C20-C), and 80 (C20-E) cfh. The weld made using the 40-cfh helium flow had the best bend ductility. The weld made using 80 cfh was only slightly less ductile and the welds made using 30 cfh of helium was considerably less ductile at room temperature and slightly less ductile at 75° C. There is probably an optimum helium flow between 40 and 80 cfh of helium, below this optimum not enough gas is provided to the weld area to give adequate protection from the air, at higher flows the gas becomes turbulent and air is entrapped in the helium envelope.

Argon was used with the $^5/_8$-in. nozzle to compare it with helium for shielding ability. Work done by previous investigators has shown the optimum argon flow for a $^5/_8$-in. nozzle to be about 15 cfh.[2] The weld (C20-F) was made using a fixed electrode with a $^3/_{16}$-in. nozzle to work distance and 15 cfh argon. The weld bead was narrow and had deep grooves at each fusion line. Bend tests showed this weld to be less ductile than welds made using 40 cfh of helium.

All weld beads had their surface oxidized when the ceramic cup was used. This oxidation appears to be only surface oxidation occurring after the weld

Table 7—Bend-Test Data for Welds Made in Air, Welds Stress Relieved 1 Hr at 1800° F in Hydrogen

Weld no.	Type of shield	Gas flow, cfh: Cup	Backing	Trailing shield	Permanent bend angles, degrees at 25° C	75° C
C20-A	$^3/_8$-in. cup	40	30	..	0, 0, 10, 20, 7.5[b]	2, 4, 4, 6, 16, 6.4
C20-B	$^5/_8$-in. cup	30	30	..	6, 10, 10, 14, 20, 20, 20, 30, 30, 17	20, 30, 40, 40, 40, 45, 45, 65, 65, 85, 48
C20-C	$^5/_8$-in. cup	40	30	..	10, 16, 30, 30, 35, 40, 50, 50, 50, 55, 37	35, 45, 45, 55, 70, 70, 80, 85, 85, 90, 66
C20-D	$^5/_8$-in. cup	40	30	..	Not tested at 25° C	2, 6, 18, 30, 40, 40, 50, 50, 60, 60, 70, 80, 80, 90, 90NF, 90NF, 54
C20-E	$^5/_8$-in. cup	80	30	..	4, 10, 14, 20, 40, 40, 40, 50, 60, 31	18, 30, 45, 50, 60, 70, 70, 70, 90NF[a], 57
C20-F	$^5/_8$-in. cup	15 (argon)	30	..	8, 14, 18, 20, 20, 25, 30, 30, 35, 65, 26	2, 8, 20, 30, 30, 40, 50, 60, 60, 90NF, 39
C20-G	Trailing shield	40	30	30	0, 30, 30, 40, 40, 50, 55, 60, 70, 46	2, 8, 60, 75, 80, 80, 80, 85, 85, 90, 90NF, 67
C20-H	Plastic bag	40	30	..	0, 8, 35, 14	16, 50, 60, 80, 90NF, 59
C20-I	Plastic bag	40	15	..	0, 0, 6, 30, 40, 40, 45, 23	40, 50, 50, 60, 65, 70, 70, 90NF, 62
C20-J	$^1/_8$-in. cup	40	20	..	0, 16, 20, 20, 14	2, 40, 60, 70, 43

(a) NF = no fracture, 90° is limit of equipment.
(b) Average values for each set of samples underlined.

has solidified and has no effect on weld ductility.

Leading- and Trailing-Shield Unit. It was originally thought that molybdenum weldment ductility could be improved by use of a trailing shield similar to those used to shield titanium to protect the complete weld. The trailing-shield unit (shown in Fig. 3(*b*)) consisted of an inert-gas-shielding cup to shield the electrode and molten pool and a leading shield to protect the molybdenum ahead of the arc.

Welds made using this unit had only slightly higher ductility than welds made with the ceramic cup. The weld bead had a bright surface when the trailing shield was used. However, as was shown with the ceramic cup, surface oxidation after the weld had solidified did not appear to affect weldment ductility. A trailing shield would be useful where multipass welds are made to facilitate cleaning between passes.

Leading Shield. It was shown in work done with the shielding cup and the leading-trailing shield that protection of the solidified weld was not necessary to produce welds with room-temperature ductility. However, it was believed that the leading portion of the leading-trailing shield unit might have improved weldment ductility by preventing oxidation of the unwelded joint ahead of the molten weld pool. Oxidation of the unwelded portion of the joint would cause a loss in ductility in a material such as molybdenum which is embrittled by minute quantities of oxygen.

The results of the bend tests on a weld made using the leading shield were inconclusive. The weld became badly oxidized during the stress relief and the ductility of a pilot weld made using the inert-gas-shielding cup was low, indicating the possible presence of contaminants in the shielding gas. Future work is planned using the leading shield.

Plastic-Bag Shield. The plastic bag was used to shroud the welding area much the same as the dry box. The bag was purged of air by flowing helium through it, and a positive pressure of helium was maintained for welding. It was thought that this would provide an improved atmosphere for welding of molybdenum in air.

Welds made using this method (C20-H and C20-I) had gross porosity at the fusion line. This porosity in welds made in the plastic bag may have been due to one of the following: first, the pressure in the bag was greater than pressure during welding with a cup or trailing shield. Gases formed in the molten molybdenum may not have been able to escape as readily due to the increased pressure. Second, gas flow was not directed on the joint by a nozzle; this may have caused any air in the bag to be drawn into the weld area. Air may have leaked into the bag through leaks, especially in the case of weld C20-H when the bag had a hole burned into it at the start of the weld. Finally, the weld penetration was not so great in these welds, using the same current, voltage, and speed as in previous welds when using the special jig designed for welding in the bag. If the jig chilled the weld faster than normal, the weld may have solidified before the gases formed during welding had an opportunity to escape. However, the mass of the copper jig used for the welds made in the bag was less than the mass of the jig used for other welds made in the dry box and in air and probably did not produce a more rapid chilling. Another weld (C20-J) was made using this jig and a $\frac{1}{2}$-in. diam ceramic shielding cup without the bag. The groove formed by the hold-down plates was steeper than that used in the other jig and the electrode had to extend further from the cup. This weld was not protected as well as other welds made in air. This weld also had a large amount of porosity, which would indicate that the porosity of welds made in the plastic bag was not due to greater gas pressure in the bag.

Dragging Shield. In order to improve the welding technique for welding molybdenum outside the dry box, a shield was devised which might simulate welding in the dry box as nearly as possible. This shield consisted of a chamber which was dragged along in contact with the sheet being welded. Figure 3*d* shows the dragging shield in welding position. The shield was purged with helium and a flow of helium was maintained throughout the welding operation.

As with the leading shield, the bend-test results were inconclusive. It is believed that the shielding gas was contaminated. The weld also became badly oxidized during the stress-relief treatment which may have embrittled it to some extent.

Weld Porosity

Radiographs of molybdenum weldments used in the study showed that: (1) butt welds made in the dry box and in air had varying amounts of porosity near the fusion line; (2) bead-on-plate we'ds made in the dry box and in air contained no porosity.

Gross porosity was found in welds made in the plastic bag as discussed thoroughly in a previous section. There are three possible reasons for the porosity found in butt joints made in air. First, after being exposed to air for a period of time, slight oxidation might occur along laminations in the sheet near the sheet edge. The cleaning method used might not be able to remove this oxide, and the oxide might vaporize or be reduced by residual carbon during welding. Second, the backing gases coming through the butt joint ahead of the arc might cause turbulence in the shielding gas, drawing air into the shield. This oxidation could be the cause of the porosity. Shield interruptions by backing gases would not occur in the case of bead-on-plate welds. Third, the porosity could be caused by contaminants in the shielding gas. Since the equipment is idle for periods of time, moisture is picked up and might be a source of contamination. However, since no porosity was found in bead-on-plate welds, the first two reasons appear more valid.

One butt weld was made in the dry box to determine if the porosity found in butt welds made in air was due to contaminated shielding gases, shield interruption or to oxides or entrapped air in laminations near the sheet edge. This butt weld had a slight amount of porosity and was comparable with the least porous welds made in air. This would indicate that the greatest portion of the porosity found in butt welds made in air was due to contaminated shielding gas or shield interruption while a small portion was due to oxides or entrapped air on the sheet edges. Even though weldment ductility could not be related to the amount of porosity in the welds tested, steps should be taken to eliminate porosity since it is an indication of the presence of oxygen in the weld.

Tungsten Contamination

While conducting welding studies in air, it was noted that the tip of the tungsten electrode was sometimes molten and small drops of tungsten were seen dropping into the molten molybdenum weld pool. Tungsten contamination may be the cause of some of the low bend angles found in tungsten-arc welds in molybdenum. This tungsten contamination was not noticed in welds made in the dry box, either because the arc is too distant from the viewports to notice it or the electrode was cooled better, since it did not protrude from the collet as far as required when a cup or other type of shield was used outside the dry box. A series of tests was made in an attempt to determine the extent of tungsten contamination.

The sheet and electrode were weighed to the nearest 0.1 mg immediately before welding and again after welding to determine weight losses or gains. Both sheet and electrode were found to lose weight during welding making it impossible, by this method, to determine the actual extent of tungsten contamination. Molybdenum weight losses

Table 8—The Effect of Tungsten on the Bend Ductility of Molybdenum Weldments at 25° C

Weld no.	*Tungsten added, w/o*	*Permanent bend angle at fracture, deg*[a]
C20-7a	None	6, 6, 14, 20, 30, 30, 30, 30, 80, **27 3**
C20-7b	3.2	0, 0, 10, 12, 12, 14, 20, 30, 35, **14 6**

(a) Average value for each set of samples shown in bold type.

occurred in air probably as a combination of oxidation and vaporization, however, in the best dry-box atmosphere molybdenum weight loss was primarily due to vaporization.

One electrode was weighed, used for four welds in the dry box, and reweighed. The total tungsten weight loss was 0.9 mg which was calculated to be 0.06 mg per inch of weld. Assuming complete pickup in the weld metal, the contamination amounted to 0.003 w/o tungsten.

Urbain[3] used a radioactive tracer of tungsten (W-187) with a half life of 24.1 hr to determine the extent and location of tungsten losses. He found that most of the tungsten loss was in the weld metal with the remaining losses either appearing as condensed vapor on the base metal or lost as fumes of tungsten oxide. Thoriated tungsten used in this study would cut down the losses. Total weight losses found by Urbain on welds in stainless steel using d-c straight polarity were about double those calculated in this study using thoriated-tungsten electrodes.

Another source of tungsten contamination may occur when the arc is struck. In order for the automatic head to strike an arc, the electrode contacts the plate and is then pulled back a preset distance. When the electrode makes contact, the molybdenum may become contaminated with tungsten near the start of the weld. One weld, whose bend specimens were tested in order from the start of the weld, had its lowest bend angles near the weld start. These low bend angles may have been due to tungsten contamination.

To determine the effect of tungsten contamination, a weld was made with a tungsten addition to the last one-half of the weld. The tungsten was added as a piece of zirconiated tungsten electrode laid in a butt joint. The amount of tungsten in the weld was calculated to be about 3.2 w/o. This was considerably more tungsten than would be expected under normal welding conditions. The bend-test data for this weld (Table 8) indicates that the weldment ductility was lowered by the addition of tungsten. As can also be seen from these data, the bend ductility was also lower than expected for a weld made in a high-purity dry-box atmosphere without a tungsten addition. This may have been due to the fact that this weld became badly oxidized during the stress-relieving treatment, possibly contaminating the weld to some extent. The addition of 3.2 w/o tungsten to the weld did not appear to have lowered the ductility of the weld to as great a degree as had been anticipated. If this large an addition of tungsten did not greatly affect the weldment ductility, then the small quantities picked up during welding may not have serious effects.

Table 10—Bend-Test Data at 25° C for Sheet Used in the Consistency Run Stress Relieved 1 hr at 1800° F in Hydrogen

Sheet no.	*Carbon content, w/o*	*Permanent bend angle at fracture, deg*[a]
C21	0.020	90NF[b], 90NF, 90NF, 90NF, 90NF, **90NF**
C22	0.015	90NF, 90NF, 90NF, 90NF, 90NF, 90NF, **90NF**
C23	0.017	90NF, 90NF, 90NF, 90NF, 90NF, **90NF**
C24	0.020	6, 20, 90NF, 90NF, 90NF, **59**
C25	0.017	90NF, 90NF, 90NF, 90NF, 90NF, **90NF**
C26	0.021	60, 60, 90NF, 90NF, 90NF, **78**

(a) Average values for each set of samples shown in bold type.
(b) NF = no fracture.

Consistency Run

A consistency run was made to determine if inert-gas-shielded tungsten-arc welds could be produced with the same ductility in sheet from different heats of arc-cast carbon-deoxidized molybdenum. Six heats of molybdenum of about the same carbon content were used for this study. Half of the specimens were welded in the dry box and the other half were welded in air using the best welding conditions found.

Material

Molybdenum from six different heats containing about 0.020 w/o carbon was

Table 9—Fabrication Data for $^1/_{16}$-in. Carbon-Deoxidized Molybdenum Sheet Used in the Consistency Run

Sheet no.	*Carbon content, w/o*	*Initial breakdown*	*Intermediate working*	*Finish rolling*
C21	0.020	Extruded from $6^1/_2$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr at 2600° F.	Rolled from $3^{21}/_{32}$-in. round to 1 x 4-in. bar at 2300° F. Annealed 1 hr at 2300° F.	Rolled[a] to 0.060 in. thick at 1800–2200° F.
C22	0.015	Extruded from $7^1/_{16}$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr. at 2600° F.	Rolled from $3^{21}/_{32}$-in. round to 1 x 4-in. bar at 2300° F. Annealed 1 hr at 2600° F.	Rolled[a] to 0.060 in. thick at 1800–2200° F.
C23	0.017	Extruded from $6^5/_8$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr at 2900° F.	Rolled from $3^{29}/_{32}$-in. round to 1 x 4-in. bar at 2300° F. Annealed 1 hr at 2300° F.	Rolled[a] to 0.060 in. thick at 1800–2200° F.
C24	0.020	Extruded from $6^5/_8$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr at 2600° F.	Forged from $3^1/_2$-in. round to 1 x 4-in. bar at 2400° F. Annealed 1 hr at 2500° F.	Rolled[b] to 0.060 in. thick at 1800–2200° F.
C25	0.017	Extruded from $6^5/_8$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr at 2600° F.	Forged from $3^{15}/_{16}$-in. round to 1 x 4-in. bar at 2300° F. Annealed 1 hr. at 2600° F.	Rolled[a] to 0.060 in. thick at 1800–2200° F.
C26	0.021	Extruded from $6^5/_8$ in. diam to $4^1/_4$ in. diam at 2300° F. Annealed 1 hr at 2800° F.	Forged from $3^{13}/_{16}$-in. round to 1 x 4-in. bar at 2300° F. Annealed 1 hr at 2600° F.	Rolled[b] to 0.060 in. thick at 1800–2200° F.

(a) Sheet was cross rolled.
(b) Sheet was not cross rolled.

used for this study. Fabrication by normal commercial practice was specified. However, the sheet was fabricated in slightly different manners, as shown in Table 9. Bend specimens were tested from each of the sheets after they had been stress relieved at 1800° F for 1 hr in hydrogen. The bend-test data are given in Table 10.

Sheets C24 and C26 showed low-room-temperature ductility. Metallographic examination of the sheets showed a coarse-grained structure for C24 and C26. The remaining sheets were more fibered, C21 showing the most fibering. All sheets except C24 and C26 were cross rolled from the sheet bar.

As will be discussed in a later section, welds in Sheets C21, C22, and C23 were usually more ductile than welds in C24, C25, and C26. The only major difference which was found in the available fabrication data was the method of fabricating the sheet bar. A similar ranking of the sheet ductility might also have been evident if the bend tests could have been carried out to fracture for all specimens.

Procedures

Welding procedures used for the consistency run were those developed in the earlier work of this study. The sheet specimens were split into two groups, one to be welded in the dry box, the other to be welded in air. All welds were stress relieved at 1800° F for 1 hr in flowing tank hydrogen. Testing procedures were the same as described earlier in the report. Procedures are listed in Table 11. The results of this study were difficult to interpret, so a statistical analysis was made of the bend-test data.

Results

From the data obtained by bend testing, it was difficult to determine if the differences between heats were significant. A statistical analysis was made of the data to determine significant differences. The analysis first showed that the standard error was 21.5° of bending for all specimens tested. When the welds made in the dry box and the welds made in air were considered separately, temperature had a significant effect on weld ductility, much more so for the welds made in air. A significant difference in weldment ductility also was found for the six heats of arc-cast molybdenum. This difference was greater for welds made in air, probably due to contamination during welding. The analysis also showed a possible significant difference between welds made in air and those made in the dry box, the welds made in the dry box being more ductile and consistent.

Table 11—Procedure for Consistency-Run Welds Made in the Dry Box and in Air

Procedure or condition	*Welds made in the dry box*	*Welds made in air*
1. Cleaning procedure	Chromic-acid etch	Chromic-acid etch
2. Sheet condition	As rolled	As rolled
3. Shielding device	Dry box	$^5/_8$-in. ceramic cup
4. Ultimate vacuum	0.1 micron of mercury atmosphere gettered	.....
5. Atmosphere	Grade A helium	Flowing Grade A helium
6. Gas flow	.....	Cup—40 cfh, backing—30 cfh
7. Current	210 amp	212–240 amp
8. Arc voltage	20 volts	16–16.5 volts
9. Weld speed	12 ipm	12 ipm

Table 12—Average Bend Angle and Factors for Determining Significant Differences for Heats Tested in Consistency Run

		—25° C[a]—		—75° C[a]—		—Average[b]—	
Atmosphere	*Rank*	*Heat*	*Avg bend angle, deg*	*Heat*	*Avg bend angle, deg*	*Heat*	*Avg bend angle, deg*
Dry box	1	C23	64.0	C22	74.5	C23	69.0
	2	C22	60.8	C23	74.0	C22	67.6
	3	C21	44.7	C25	68.1	C21	55.8
	4	C24	44.5	C21	66.9	C24	55.3
	5	C25	38.0	C24	66.2	C25	53.0
	6	C26	37.6	C26	57.4	C26	47.5
Air, helium shield	1	C21	36.4	C21	67.9	C21	52.1
	2	C23	28.5	C23	58.7	C23	43.6
	3	C22	21.7	C22	57.7	C22	39.7
	4	C26	17.8	C25	51.2	C25	34.1
	5	C25	17.0	C26	40.8	C26	29.3
	6	C24	8.2	C24	31.0	C24	19.6

(a) Significant difference (probability level of risk, 5 per cent) 13.3 deg. Highly significant difference (probability level of risk, 1 per cent) 17.6 deg.

(b) Significant difference (probability level of risk, 5 per cent) 9.4 deg. Highly significant difference (probability level of risk, 1 per cent) 12.4 deg.

Table 13—Significant Differences Between Groups of Heats, 5 Per Cent Probability Level of Risk

Testing temperature	*No significant difference*	*Significant difference*	
		Between:	*And:*
	Welds Made in Dry Box		
25°C	C23, C22 C24, C25, C26, C21	C23, C22	C21, C24, C25, C26
75°C	C22, C23, C25, C21, C24 C26, C25, C21, C24	C22, C23	C26
Average	C23, C22 C25, C26, C21, C24	C23, C22	C21, C24, C25, C26
	Welds Made Outside Dry Box		
25°C	C21, C23 C26, C22, C23, C25 C24, C25, C26	C21 C23, C22, C21	C22, C26, C25, C24 C24
75°C	C21, C23, C22 C23, C22, C25 C26, C24 C25, C26	C21 C23, C22, C21 C25, C21, C23, C22	C25, C26, C24 C24, C26 C24
Average	C21, C23 C22, C25 C25, C26 C22, C23	C21 C23, C21 C23, C22, C21 C25, C26, C21, C23, C22	C22, C25, C26, C24 C25, C26, C24 C24, C26 C24

The greater difference for different heats of molybdenum welded in air may have been due to the welding procedure. Welds made one day were more ductile than welds made the following day. The welding equipment may have picked up moisture, even though helium was allowed to flow through the equipment for several minutes and welds were made in scrap to dry out the equipment before welding. Another possibility is that the surface of the molybdenum sheet may have become slightly oxidized overnight, even though kept in a desiccator until being welded.

An examination of the average bend-angle data given in Table 12 was made to determine between which heats or groups of heats significant differences in weldment ductility existed. Table 13 indicates which groups of heats possessed no significant difference and also indicates between which groups of heats a significant difference lies. This table is based on significant differences calculated for a 5 per cent probability level of risk.

An examination of the bend-test data for the consistency run indicated that welds in Heats C21, C22, and C23 were more ductile than welds in Heats C24, C25, and C26. From the fabrication data for these heats (Table 9), the only difference found which might explain this is that the sheet bar was rolled in the case of C21, C22, and C23, while it was forged in the case of C24, C25, and C26. However, the fabrication data on the six commercial heats used in this study are not so complete as would be desired.

Summary

Weldments were made in the dry box to determine the effects of sheet-cleaning procedures, recrystallization of sheet prior to welding and atmosphere purity on the ductility of molybdenum weldments. Preliminary studies also were made of supplementary shielding methods for welding molybdenum outside the dry box. The information gained from these two studies was then used for a consistency run to determine if weldments with consistent ductility could be made in different heats of arc-cast carbon-deoxidized molybdenum. Bend tests were made at room temperature and at 75° C. All welds showed some ductility at room temperature. The experimental work showed that the welds made in the dry box had better and more consistent ductility than made in air.

The studies made in the dry box showed that none of the cleaning procedures studied was outstanding insofar as final weldment ductility was concerned. A chromic-acid solution (95 v/o H_2SO_4, 4.5 v/o HNO_3, 0.5 v/o HF, and 18.8 g/l Cr_2O_3) was more desirable because of its ease of use. It would also be the best method for cleaning complex shapes for welding. Recrystallization of the fibered sheet before welding had no effect on weldment ductility. The weld made in the lower purity atmosphere was slightly less ductile than welds made using a high-purity dry-box atmosphere.

Of the three shielding methods studied in air, the two best methods produced weldments of about the same ductility. These methods were the inert-gas-shielding cup and the leading-trailing shield unit. A more extensive study was made of the cup shield. It was found that a $^5/_8$-in. gas nozzle was a more effective shield for welding molybdenum than a $^3/_8$-in. nozzle, that helium was more effective and produced a better weld contour than argon, and that the optimum helium flow using the $^5/_8$-in. cup was about 40 cfh.

The leading-trailing shield unit protected the unwelded joint ahead of the arc, the molten weld pool, and the solidified weld. Outside of protecting the molten weld pool, the most important function of this unit was the protection of the unwelded joint ahead of the molten pool from oxidation. Surface oxidation after the weld was solidified did not appear to affect ductility. The other shield studied was a plastic bag, purged of air by flowing helium. This shield was to shroud the weld from air much the same as a dry box. This shield was abandoned because it was cumbersome, and did not allow a clear view of the weld being made, the welds contained gross porosity and were no more ductile than when using the inert-gas-shielding cup or the leading-trailing shield unit.

The results of the consistency run on welds made in the dry box showed a significant difference in ductility for welds made in different heats of arc-cast carbon-deoxidized molybdenum of about the same carbon content. A greater difference was found between heats for welds made in air, probably due to contamination of some of the welds during welding. The ductility of welds made in air was lower and much less consistent than welds made in the dry box. This shows that further work is required to improve shielding and welding methods outside the dry box.

The investigation of the ductility of molybdenum weldment made in air showed a wide variation in results. This wide variation might be due to several causes which should be eliminated if possible by a test program. The most likely source of trouble appears to be water vapor which could be picked up in varying amounts from the welding equipment. Present attempts to dry out equipment before use may require improvement or the welding should be carried out in a controlled-humidity room.

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EFFECTS OF NITROGEN ON THE SOUNDNESS AND DUCTILITY OF WELDS IN MOLYBDENUM

Results of study indicate that nitrogen does not cause weld porosity or hot cracking but is detrimental to low-temperature ductility

BY W. N. PLATTE

ABSTRACT. The acquisition of nitrogen by molybdenum weld metal and the effects of nitrogen on mechanical and metallurgical properties were studied. Molybdenum weld metal acquires nitrogen rapidly in argon welding atmospheres containing 1% N_2 or less. Nitrogen does not cause weld porosity or hot cracking but is detrimental to low-temperature ductility. For maximum weld ductility the nitrogen in the weld metal should be held to limits close to the original metal composition.

Introduction

The causes of cracking, porosity and low ductility in molybdenum welds have not been completely established. Weld-metal and base-material contamination was suspected as a source of difficulty. The effects of oxygen and nitrogen on the properties of welds in molybdenum were studied because in any gas-shielded welding process contamination from the presence of air components is possible. The problems involved in oxygen contamination were presented in an earlier paper.[1] Nitrogen contamination could be as serious as that of oxygen because the nitrogen atom is small and can exist interstitially in the molybdenum lattice. Nitrogen is ordinarily diatomic and as such is not easily acquired by molybdenum. In the presence of the electric arc the nitrogen becomes monatomic and in some cases may exist as nitrogen ions with valences of +1 to +3.[2] In the monatomic or ionic form, nitrogen is easily acquired by molybdenum. The combination of these factors suggests that nitrogen could have a strong influence on the properties of welds made in molybdenum. Deliberate nitrogen-contamination studies of the argon-gas shield were made to determine the nature of nitrogen contamination and its effects on soundness and mechanical properties of molybdenum weld metal.

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Experimental Techniques

Welding tests were made using a previously described chamber which had been purged of atmosphere contaminates.[1] High-purity dry nitrogen was used and mixed with welding-grade argon by the mixing system shown in Fig. 1. The welding atmosphere was sampled using the technique shown in Fig. 2. Collected samples of the welding atmospheres were analyzed using mass spectrometric techniques.

Weld test beads were made in molybdenum containing 0.06% C and incremental additions of nitrogen were made to the argon welding atmosphere. The nitrogen in the atmosphere was varied from 0.1% to 85% with the remainder in each case being argon. No deliberate additions of oxygen were made in these tests.

Welding data are given in Table 1. The welding current was maintained at 180 amp. The arc voltage shifted with the nitrogen concentration in the welding atmosphere, Fig. 3. The amount of material melted with a given arc travel speed and welding current increased with the nitrogen concentrations and reflects the increase in the arc energy due to nitrogen additions. Melting may also have been increased by the reduction in the melting point due to a molybdenum-nitrogen eutectic. However, the presence of such a eutectic seems doubtful because hot center-bead cracking was not observed in weld beads made with nitrogen additions up to 50%. Hot tears and gross porosity occurred with 85% nitrogen in the welding atmosphere. Crater cracks occurred in all welds made under atmospheres containing 2.5% nitrogen or more.

Weld beads made in low- and high-nitrogen atmospheres are shown with their X-ray pictures in Figs. 4 to 6. The increase in bead width is proportional to the increase in nitrogen concentration in the atmosphere. The absence of hot center-bead cracks is evident. Porosity is observed only in the specimen made under an atmosphere of 85% nitrogen.

The molten molybdenum acquires

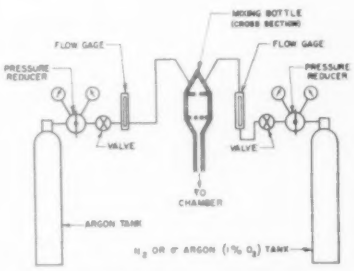

Fig. 1 Schematic gas-mixing system

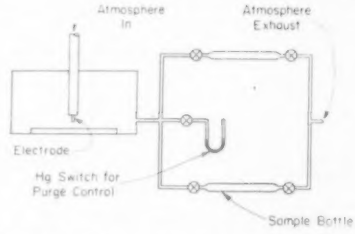

Fig. 2 Schematic of gas-sampling system for welding chamber

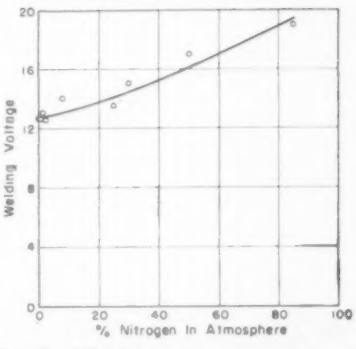

Fig. 3 Welding voltage vs. nitrogen in atmosphere

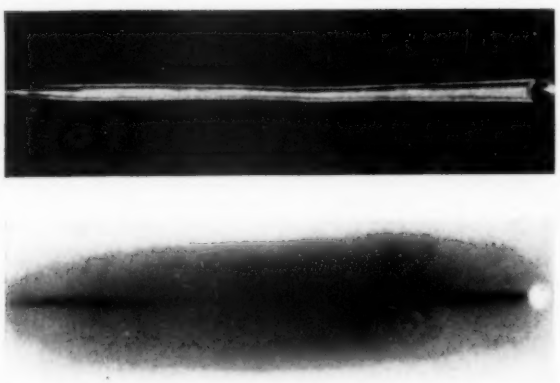

Fig. 4 Weld made under atmosphere 0.1% N_2 balance argon

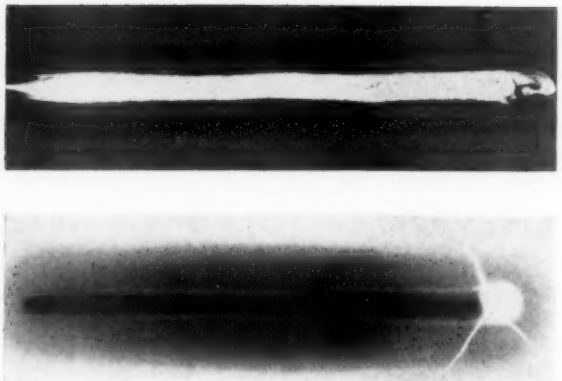

Fig. 5 Weld made under atmosphere 50% N_2 50% argon

nitrogen during the arc-welding operation. Composition data for the welds made in nitrogen-bearing atmospheres are shown in Table 2 and the relationship between nitrogen in the weld and nitrogen in the atmosphere is shown in Fig. 7. These data show that the major portion of the possible nitrogen content is acquired by the weld metal when the nitrogen is less than 1% in the welding atmosphere. Welding-grade argon frequently contains 0.1% nitrogen. The nitrogen in the weld metal, using welding-grade argon, was 0.055% as compared to 0.003% in the original sheet stock. Thus, the amount of nitrogen in welds made with welding-grade argon could be as much as 0.055%.

Metallographic examination of the weld metal fused under nitrogen-bearing atmospheres shows that some of the nitrogen is present in the form of nitrides. As the nitrogen in the atmosphere is increased, the number and size of the nitrides formed in the weld metal increases. As the nitrogen contents of the welds increase, the tendency to form grain boundary films and nitrides in the grain matrix both increase, Figs. 8 to 12. The weld made under high-purity helium was used as a control and shows no contamination, by chemical analysis, Fig. 8. The nitrogen in the grain matrix near the grain boundary has been precipitated at the grain boundaries, and heavy, continuous films appeared in the boundaries when the nitrogen concentration in the weld metal exceeded 0.067%. The control sample, Fig. 8, shows no continuous films. The difference in grain height should not be mistaken for a film in the control specimen.

The welds made in atmospheres containing nitrogen in the range 0.1% to 85%, with the balance argon, were tested in bending over a range of temperatures. The bend-test data are given in Table 3. The testing techniques were described in an earlier paper.[1] The relationship between the

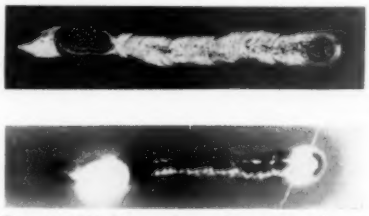

Fig. 6 Weld made under atmosphere 85% N_2 15% argon

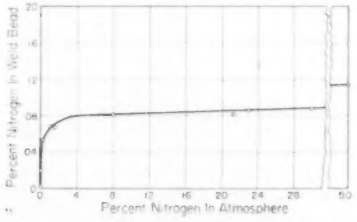

Fig. 7 Nitrogen in weld bead vs. nitrogen in atmosphere

Table 1—Welding Data for Welds Made with Nitrogen Additions to the Atmosphere

Sample	*Atmosphere analysis*	*Weld current, amp*	*Weld voltage*	*Arc-travel speed, ipm*	*Comments*
G18	A 92% N_2 8%	170	13–14	7.35	Clean, bright bead. Flow lines in bead formed while cooling
G18a	A 92% N_2 8%	175	14	6.36	Bright, clean bead. Strain lines. Some are blow
G19	A 75% N_2 25%	180	13.5	6.02	Difficulty with high-frequency stabilizer. No spark. Increased gap to 0.038. Arc length may have been in error. Weld clean, bright
G20	A 70% N_2 30%	180	15.5	5.6	No crack after welding. Cracked through crater three days later upon slight flexing
G21	A 50% N_2 50%	170	17	5.9	Clean, bright bead. Crater cracks
G22	A 98.5% N_2 1.5%	185	13	6.2	Clean, bright bead but narrow. 90–100% penetration. Crater crack
G23	A 97.5% N_2 2.5%	175	12.5	6.75	Clean, bright bead. No visible cracks
G24	A 99.0% N_2 1.0%	180	12.5	6.75	Clean, bright, narrow bead, no cracks
G25	A 99.9% N_2 0.1%	180	12.5	6.15	Clean, bright, narrow bead, no cracks
G26	A 15% N_2 85%	170	19	6.45	Wide rough bead, porosity in crater. Hot tears near end of bead. Arc had difficulty starting

Table 2—Nitrogen Picked Up by Molybdenum during Welding in Argon-Nitrogen Atmospheres

Sample no.	*Percent nitrogen in atmosphere*	*Percent nitrogen in weld bead*
G25	0.1	0.055
G24	1.0	0.068
G22	1.5	0.067
G23	2.5	0.163
G18	8.0	0.081
G19	25.0	0.086
G20	30.0	0.088
G21	50.0	0.115
G26	85.0	0.090
AG30	0.1	0.02
Unwelded	..	0.003

Table 3—Bend-Test Data for Samples Welded in Nitrogen-Bearing Atmospheres

Spec. no.	Nitrogen addition to arc atmos., %	Test temp., °F	Thickness	Width	Load at prop. limit, lb	Max. load, lb	Load at fracture, lb	Inches deflection at fracture
G25	0.1	320	0.060	0.2515	19	55	...	No Fracture
	0.1	280	0.059	0.2515	13	56	...	No Fracture
	0.1	240	0.0595	0.2515	23	57.8	...	No Fracture
	0.1	200	0.0595	0.2515	19	63	...	No Fracture
	0.1	180	0.059	0.251	34.5	62	...	No Fracture
	0.1	160	0.060	0.2495	39.5	65	59.5	0.295
	0.1	79	0.060	0.251	54	...	79.4	0.097
	0.1	0	0.0595	0.251	72	...	100	0.063
	0.1	−80	0.060	0.2515	76	...	104	0.039
	0.1	−160	0.0595	0.251	...	...	106	...
G24	1.0	320	0.0595	0.248	18	57	...	No Fracture
	1.0	280	0.0505	0.250	10	38	...	No Fracture
	1.0	260	0.060	0.248	17.5	...	54	0.119
	1.0	240	0.057	0.248	28.2	52.8	39	0.412
	1.0	240	0.060	0.248	20	...	59.5	0.149
	1.0	160	0.060	0.250	38	...	67	0.193
	1.0	79	0.058	0.2485	48	...	64	0.029
	1.0	0	0.060	0.250	66	...	83	0.009
	1.0	−80	0.0525	0.249	63	...	75	0.002
	1.0	−160	0.060	0.2505	90	...	101	0.002
G22	1.5	480	0.059	0.252	12	54	...	No Fracture
	1.5	440	0.060	0.252	13	54	...	No Fracture
	1.5	400	0.0595	0.252	12	...	53	0.192
	1.5	320	0.060	0.2525	16.3	...	53	0.126
	1.5	240	0.059	0.2525	28	...	58.2	0.132
	1.5	160	0.0595	0.2525	38.8	...	52	0.023
	1.5	79	0.0595	0.2525	50	...	66	0.017
	1.5	0	0.0595	0.2525	64	...	81.5	0.009
	1.5	−80	0.059	0.2515	77	...	90	0.002
G23	2.5	320	0.060	0.2505	13	51	...	No Fracture
	2.5	280	0.060	0.2505	16.5	51.2	...	No Fracture
	2.5	260	0.0595	0.2505	15	55.7	...	No Fracture
	2.5	240	0.0595	0.251	17	54	40	0.438
	2.5	200	0.060	0.251	18	...	60	0.147
	2.5	160	0.055	0.2505	18	...	49.5	0.110
	2.5	82.5	0.055	0.2505	39	...	63	0.087
	2.5	0	0.0595	0.2505	63	...	82	0.036
	2.5	−80	0.053	0.2505	63	...	76	0.003
G18A	8.0	420	0.060	0.2505	14	52.5	...	No Fracture
	8.0	400	0.060	0.251	15.5	54	...	No Fracture
	8.0	380	0.060	0.2515	16	56.2	55.8	0.238
	8.0	380	0.060	0.251	15.5	...	56.5	0.225
	8.0	360	0.060	0.251	13	56	43.5	0.407
	8.0	320	0.0595	0.251	17	58	57	0.257
	8.0	82.5	0.0595	0.251	50	...	64	0.012
	8.0	0	0.0595	0.250	73	...	84	0.009
G19	25.0	480	0.0595	0.250	12	...	46	0.123
	25.0	400	0.059	0.250	13	...	56	0.183
	25.0	400	0.0595	0.250	15.5	61.5	...	No Fracture
	25.0	320	0.059	0.250	16.5	...	36.5	0.017
	25.0	240	0.059	0.250	21	...	48	0.058
	25.0	160	0.0595	0.250	39	...	51.5	0.029
	25.0	82.5	0.059	0.250	51	...	62	0.004
	25.0	0	0.059	0.250	66	...	78	0.002
	25.0	−80	0.0595	0.2495	...	...	73	...
G20	30.0	420	0.057	0.246	17	50	...	No Fracture
	30.0	400	0.0585	0.250	13	54.2	...	No Fracture
	30.0	380	0.059	0.250	14	54.5	52.5	0.283
	30.0	360	0.049	0.250	12	...	35.8	0.188
	30.0	320	0.0575	0.245	16.2	...	46.3	0.120
	30.0	240	0.0575	0.250	28	...	47.3	0.076
	30.0	160	0.054	0.2485	34	...	46	0.057
	30.0	79	0.052	0.250	38.8	...	50	0.029
	30.0	0	0.054	0.2455	57	...	67.5	0.009
	30.0	−80	0.054	0.249	66	...	75.5	0.002
G21	50.0	480	0.059	0.250	13	...	56	0.142
	50.0	400	0.059	0.2505	8	...	50.5	0.126
	50.0	320	0.059	0.251	7.5	...	54.5	0.097
	50.0	240	0.059	0.251	14	...	48	0.054
	50.0	160	0.056	0.251	37.3	...	45	0.014
	50.0	79	0.059	0.251	58	...	66.5	0.003
	50.0	0	0.0565	0.250	66	...	76.5	0.004
	50.0	−40	0.059	0.251	...	...	72	...
	50.0	−80	0.059	0.2505	...	...	86.5	...

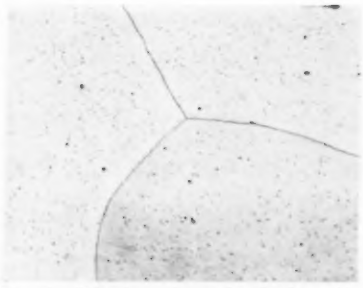

Fig. 8 Weld made under high-purity helium. No contamination from atmosphere

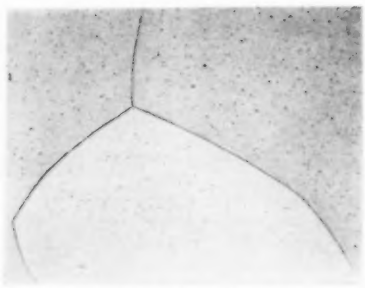

Fig. 9 Weld made under argon containing 0.1% nitrogen, weld metal 0.055% nitrogen

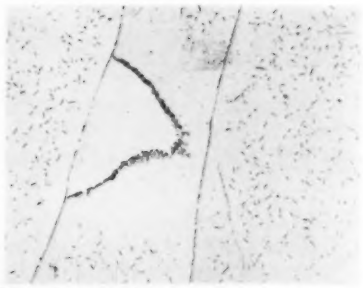

Fig. 10 Weld made under argon containing 8% nitrogen, weld metal 0.081% nitrogen

bend deflection and the temperature of testing is shown in Fig. 13. Increasing the nitrogen in the welding atmosphere shifts the temperature of maximum ductility to higher values. This relationship is clarified if the per cent nitrogen in the weld bead is related to the temperature at which ductile behavior is obtained in bending, Fig. 14. This transition temperature was taken arbitrarily as the temperature at which 0.4 in. deflection or 100° angle of bend was obtained. From this curve it appears that as the nitrogen content of the weld metal is decreased the temperature at which 0.4 in. deflection can be obtained is decreased. One of the points shown for the minimum nitrogen concentration was obtained from a weld made in helium which is low in nitrogen. The other point is not strictly applicable because it applies to unwelded recrystallized material and the effect of grain size becomes a factor. However, this point falls in the scatter band of the data obtained for welded material. The data in Fig. 14 suggest that if the nitrogen in the weld metal were maintained at a sufficiently low value it would be possible to obtain ductile weld metal at temperatures near ambient. These data are not independent of the effects of oxygen. Oxygen in the welding atmosphere could cause boundary films which shift the ductility characteristics or it could, by an oxidizing action, remove a portion of the carbon from the weld metal. A further effect of oxygen on weld properties, which will be discussed at length in another paper, is the ability of oxygen to counteract the effect of nitrogen in the welding arc and vice versa. Apparently the oxygen and nitrogen react, and in the welding chamber used the products of this reaction were removed from the weld area so that the amount of both oxygen and nitrogen were lower than would be expected for a given concentration of either one.

The temperature for completely-brittle fracture is raised by nitrogen additions to the welding atmosphere. Table 4 shows the brittle fracture (no measurable bend deflection) data for welds made in nitrogen bearing atmospheres. The correlation between nitrogen in the weld bead and the temperature of brittle fracture is shown in Fig. 15. A general trend is shown and as the nitrogen decreases the temperature of complete brittleness decreases.

The relationship between the stress required for fracture and the nitrogen concentration is shown in Fig. 16. The relationship here is somewhat uncertain because of insufficient data, but there

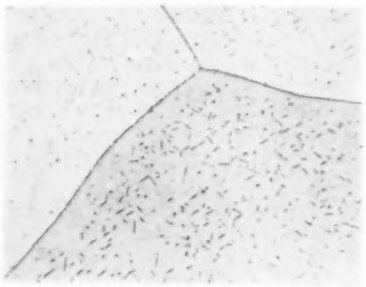

Fig. 11 Weld made under atmosphere, 50% N_2, balance argon. Weld metal 0.115% nitrogen. X 300. (Reduced by one half upon reproduction)

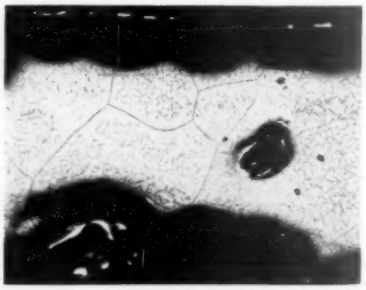

Fig. 12 Weld made under atmosphere, 85% N_2, balance argon. Weld metal 0.090% nitrogen. X 100. (Reduced by one half upon reproduction)

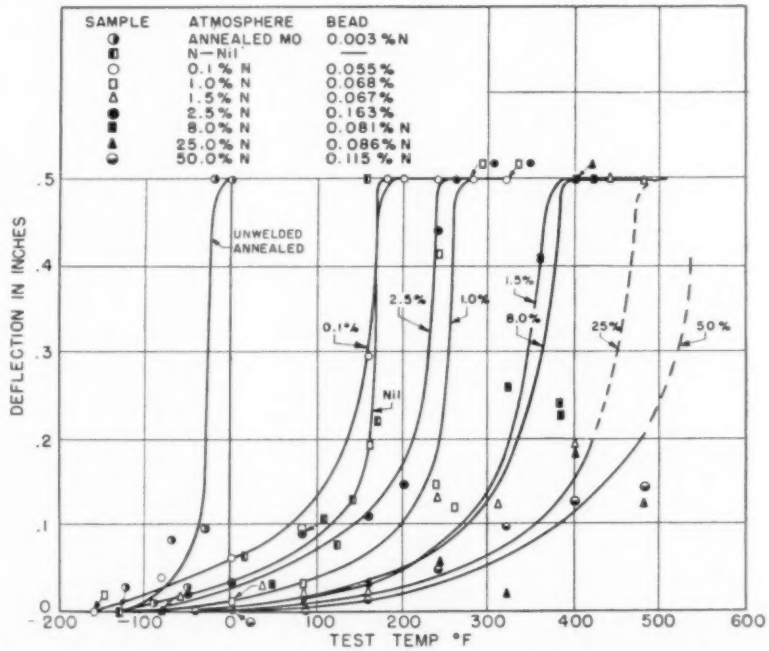

Fig. 13 Deflection vs. testing temperature for molybdenum welds made in argon with N_2 added

is a strong indication that the stress at the proportional limit is not shifted by nitrogen additions above 0.07%. A similar effect on the temperature for brittle failure can be observed in Fig. 15. The data suggest that the temperature of completely-brittle behavior does not increase with increased nitrogen in the weld metal when the nitrogen concentration exceeds 0.07%. However, nitrogen concentrations below 0.07% allow the stress for brittle fracture to increase as the temperature for failure decreases. This occurs as the nitrogen is progressively decreased.

An explanation for the change in properties can be seen in part by an examination of the metallographic samples of welds made in nitrogen-bearing atmospheres, Figs. 8 to 12. These photomicrographs show that the nitrides tend to form first in the grain boundaries and later in the body of the grain. The combination of mechanical-property data with the metallographic data suggests that with less than 0.07% nitrogen in the bead the boundary film of nitrides tends to become discontinuous. This condition could account for the reduction of the brittle fracture strength with increasing nitrogen concentrations up to 0.07%.

The boundary films implied intergranular fractures. A study of the fracture origins on the bend-test specimens from welds made in nitrogen bearing atmospheres showed that of 60 specimens 54 had their fracture origin in a grain boundary. From the remaining six specimens, two were definitely transgranular and four were of doubtful origin. This breakdown was nearly the same as found for the samples welded in oxygen-bearing atmospheres. However in the case of samples welded in oxygen, the brittle failure stress continued to decrease with increased oxygen concentration along the stress at proportional limit vs. temperature curve shown in Fig. 17. It was observed in the nitrogen studies that the temperature and stress for brittle failure remained relatively constant when the nitrogen content exceeded 0.07% in the weld metal. A possible explanation for the difference in the effects of nitrogen and oxygen may be found in the micro-mechanism of fracture.

Apparently nitrogen concentrations of 0.07% can produce boundary films of sufficient continuity to be obstacles for dislocation motion. Alers[3] has demonstrated that a pile up of dislocations can produce local stresses which reach a value sufficient to form a crack. The fracture study showed that fractures originated at grain boundaries. Hence, the cracks would have to occur at the interface of the boundary precipitates. Since both oxygen and nitrogen are known to form boundary films, a difference in the strength of this interface will probably account for the difference in the stress and temperature required for brittle fracture. The stress required to produce fracture, when the nitride film was complete at 0.07% nitrogen, is much larger than was found for even partial oxygen films.[1] The high value of stress required in the case of nitride precipitates would permit an increase in the stress and a corresponding decrease in the testing temperature required for brittle fracture. The rise in the brittle-fracture stress with decreasing nitrogen below 0.07% may be explained by the decrease in continuity of the nitride films at the grain boundaries. If the films are sufficiently discontinuous the micro cracks formed at the nitride particles may not be able to propagate at a stress sufficient for fracture with continuous films. Hence, as the nitrogen concentration decreases below 0.07%, the stress for brittle fracture should increase as the proportional limit increases. The data showed both the difference in the stress required for fracture with increasing nitrogen and the difference in stress for fracture when oxides rather than nitrides are present at the boundaries.

The data obtained on the effects of nitrogen in molybdenum weld beads indicate that if welds of maximum ductility are to be obtained, the nitrogen contamination must be reduced to a level where the weld metal nitrogen content does not differ from the base metal. The oxygen level must also be maintained at a value near that of the base material, as shown in an earlier work,[1] if full advantage is to be taken of the reduction in the nitrogen in the weld metal.

Table 4—Brittle-Fracture Stress and Nitrogen Concentration Data

Sample	*Brittle failure temp., °F*	*Ductile failure temp., °F*	*Outer fibre tensile stress for brittle failure*	*Nitrogen in bead, weight, %*	*Nitrogen in atmosphere, %*
G21	− 80	540	149,000	0.115	50.0
G21	− 40	...	124,000	0.115	50.0
G20	− 80	400	135,000	0.090	30.0
G19	− 80	460	124,500	0.085	25.0
G18a	0	380	124,500	0.080	8.0
G23	− 80	230	132,000	0.163	2.5
G22	− 80	420	133,000	0.067	1.5
G24	− 80	260	137,500	0.068	1.0
G24	−160	...	150,000	0.068	1.0
G25	−160	170	182,000	0.055	0.1
G30a	−160	120	101,000	0.020	0.1
As Rolled	−120	− 30	185,000	0.002	0.0
He 1	−240	120	201,000	0.003	0.0

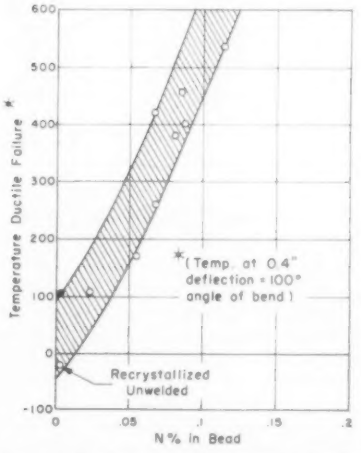

Fig. 14 Relation between ductile failure temperature of bend specimen and nitrogen in weld beads

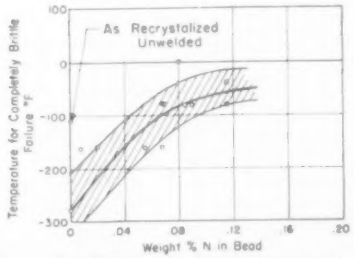

Fig. 15 Effect of nitrogen in molybdenum weld beads on the temperature for brittle fracture

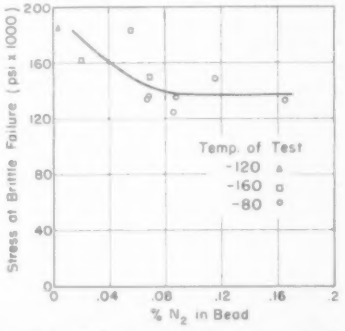

Fig. 16 Effect of nitrogen in molybdenum weld beads upon the brittle rupture stress

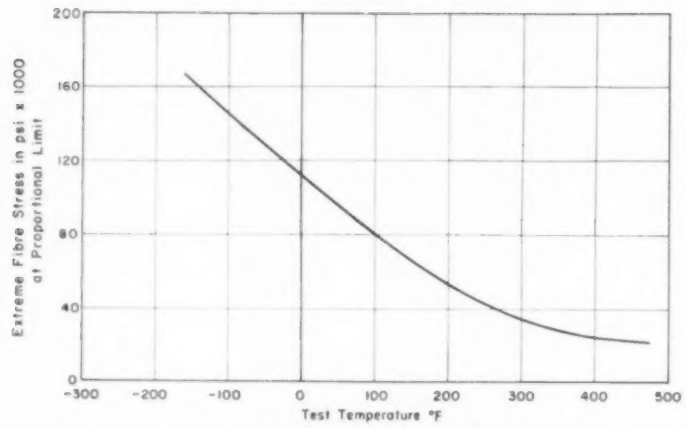

Fig. 17 Curve showing relation of calculated fiber stress at proportional limit as related to test temperature for welds made in oxygen-bearing atmospheres

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The author wishes to thank J. H. Bechtold, H. Scott and J. Heuschkel for their advice during the course of this study.

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2. W. Finkelnburg, Seminar, Westinghouse Research Laboratories.

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WELDING HEAVY SECTIONS BY THE RUSSIAN ELECTRO-SLAG PROCESS (*Continued from page 290-s*)

vertical and hot cracking is likely to occur. With correct gap between plates and sufficient penetration, the crystals grow at an angle of 45 deg and no hot cracking is observed. Oscillation of the electrode strongly affects dendritic growth.

Welding Conditions. The number of electrodes is shown in Table 2. For short welds, stationary electrodes are used. For sections 40 in. thick, 18 electrodes are used, six connected to each phase of a three-phase welding transformer. A flat bar or strip may be used instead of several wires. The electrodes should be 1.57 to 1.77 in. apart. During oscillation the outer electrode should approach to within $^1/_8$ in. of the copper mold and should hesitate there for 5 sec before reversing its motion. The speed of motion during oscillation is $15^3/_4$ to 20 ipm. The total depth of slag plus weld metal should be $2^3/_4$ to $3^1/_2$ in. The depth of slag should be 2 to $2^3/_4$ in. to assure sufficient penetration. Increasing the voltage and decreasing the current tends to prevent the weld puddle becoming too deep, which increases the risk of hot cracks. Oscillation does not change the shape of the weld trough, but prevents the growth of excessively large crystals. The best shape for the weld trough is spherical. Additions of titanium, aluminum and vanadium refine the primary grain. As a rule it is necessary to heat treat the weld after completion. There is no difficulty with porosity.

The electrode diameter is $^1/_8$ in. and the current usually is 650 to 750 amp, at 42 to 46 v. The current density is 60,000 to 70,000 amp/sq in. and the rate of deposition is 40 to 49 lb/hr. For an average plate spacing of 1.10 in. the welding time in minutes per foot of joint is $A_s = 4.89\ T/N$ where T = plate thickness in inches and N = number of electrodes, Table 3.

Flux, wire and apparatus. Fluxes AN8, AN22 and FZ 7 are used, Table 4. About 5 lb of flux is consumed per 100 lb of wire. AN22 is low in silica, is

(*Continued on page 311-s*)

Table 1—Comparison of Multiple-Pass Arc Welding with Electro-Slag Welding for 4-In. Steel Plate

	Multi-pass arc welding	*Electro-slag welding*
Time to reach maximum temperature, sec	3	640
Time during which the metal is over 1830° F, sec	2 5	95
Time during which the weld cools through the pearlite-bainite range 1290–660° F, sec	12	630
Time during which the weld cools through the martensite range 660–390° F, sec	20	1620
Width of heat-affected zone, in.	0 08	0 63

Table 2—Number of Electrodes for Various Plate Thicknesses

Plate thickness, in.	$2^3/_8$	$2^3/_8$	$2^3/_4$–4	4–6	6–8	10–16
No. of stationary electrodes	1	..	2	3	..	..
No. of oscillating electrodes	..	1	..	..	2 or 3*	3

* Only two electrodes if three-wire apparatus is not available.

Table 3—Welding Time for Various Thicknesses

Plate thickness, in.	*No. of electrodes* — *Stationary*	*Oscillating*	*Welding time, min/ft*
2	1	..	10
4	2	..	10
6	3	..	10
8	..	2	20
12	..	3	20
16	..	3	27

RELATIVE BEHAVIOR OF NOTCH-TOUGHNESS TESTS FOR WELDED STEEL

WRC-sponsored investigation is aimed at studying some of the testing methods used to measure the notch toughness of welded steel and attempts to clarify the interpretation of these tests

BY W. J. MURPHY, W. D. McMULLEN AND R. D. STOUT

SYNOPSIS. Eleven structural steels in a variety of conditions were tested using the notched slow-bend (Kinzel), Naval Research Laboratory (NRL) drop-weight and V-notch Charpy tests in order to develop a basis of comparison for these tests.

In addition to determining the Kinzel 1% lateral contraction transition temperature, the nil-ductility transition(NDT) temperature and the Charpy 10 ft-lb temperature, great use was made of specimen fracture appearance after testing to help analyze the results of each test.

A correlation between the drop-weight NDT and the Kinzel 1% lateral contraction temperatures was found to exist when Kinzel specimen behavior reflected the ability of the base material to prevent cleavage crack propagation.

A plot of NDT vs. Charpy 10 ft-lb temperature for the project steels plus steels tested at NRL revealed a scatter-band within which the two transition temperatures correlated.

Introduction

During the past ten years extensive studies have been conducted on the notch toughness of steels used in welded structures such as ships, pressure vessels and bridges. While much helpful information has resulted from these investigations there are many points upon which confusion exists. These include interpretation of laboratory test results, correlation between different laboratory tests and the correlation of test results to service performance. Attempts to resolve these difficulties have been complicated by the existence of a multitude of test specimen designs and a multiplicity of criteria by which the data are analyzed.

Although most of the test methods have been applied to unwelded steel some tests have been developed to incorporate welding as a variable, particularly when it was desired to study the effect of the welded region on the notch toughness of structural steels. Examples of these welded test specimens include the notched slow-bend test and the explosion-bulge test. In addition, the Naval Research Laboratory (NRL) drop-weight crack starter test utilizes a welded specimen but is intended to be used only to study the notch toughness of the base metal, not that of the weld zone.

The relative significance and usefulness of these testing methods have by no means been established. The work reported here was undertaken to attempt to define to what extent and under what circumstances these tests, along with the V-notch Charpy impact test, can be correlated with each other.

W. J. Murphy and **R. D. Stout** are associated with Lehigh University, Department of Metallurgical Engineering, Bethlehem, Pa., and **W. D. McMullen** is Associate Engineer, Atomic Power Division, Westinghouse Electric Co., Pittsburgh, Pa.

Presented at the 1957 AWS National Spring Meeting in Philadelphia, Pa., April 8-12.

Materials

The steels used were supplied as 1-in. thick plate. The chemical compositions of the steels are listed in Table 1.

The tensile properties of the steels in the as-rolled and in the normalized condition are listed in Table 2. The majority of the steels were received in the as-rolled condition. Where they were received in the normalized condition this is noted. When laboratory normalizing was employed this was performed at 1650° F. The T-1 steel was tested as-quenched and tempered at 1200° F.

Specimen Preparation and Testing Procedure

V-Notch Charpy Tests

Charpy specimens were cut with the longitudinal axis of the specimen parallel to the plate rolling direction and machined with the notch in the thickness direction. A total of 24 specimens were used for each series, and were tested through the transition range in order to obtain the 10 ft-lb transition temperatures.

Kinzel Tests

Kinzel specimens 3 x 12 in. were cut

Table 1—Steels and Chemical Composition

Steel			Composition, %								
Spec.	Grade	Code	C	Mn	P	S	Si	Ni	Cr	Mo	Other
A-7	...	RW	0.20	0.75	0.009	0.030	...	...	...	...	...
A-7	...	W	0.27	0.60	0.014	0.031	...	...	...	...	...
A-201	A	RB	0.12	0.48	0.010	0.022	0.18	...	...	...	...
A-201	A	Y	0.11	0.51	0.020	0.024	0.20	...	...	...	...
A-212	B	KC	0.25	0.66	0.020	0.022	0.19	...	...	...	...
A-212	B	T	0.32	0.56	0.016	0.031	0.26	...	...	...	...
A-285	B	RG	0.09	0.49	0.010	0.031	...	...	...	...	...
A-302	B	H	0.18	1.12	0.035	0.033	0.23	...	...	0.45	...
A-302	B	B	0.20	1.32	0.022	0.030	0.25	...	...	0.42	...
48s5	...	E	0.15	1.09	0.033	0.028	0.18	0.06	0.06	0.02	V—0.09 Ti—0.099 Cu—0.11
T-1	...	R	0.15	0.93	0.015	0.022	0.27	0.89	0.48	0.44	V—0.06 B—0.0031

Table 2—Tensile Properties of Steels

Steel	Condition	Yield point, psi	Tensile strength, psi	Elongation in 2 in., %	Reduction in area, %
A-7(RW)	AR	28,200	61,800	33.3	63.2
	N	38,700	58,900	37.0	67.8
A-7(W)	AR	39,500	80,200	22.8	52.3
	N	41,400	79,000	23.0	43.4
A-201(RB)	AR	28,700	56,400	36.0	67.4
	N	36,800	57,800	36.0	68.8
A-201(Y)	AR	27,600	56,300	36.3	76.8
	N	38,000	58,700	36.0	69.2
A-212(KC)	AR	36,400	71,700	31.7	61.7
	N	44,400	72,900	31.7	63.5
A-212(T)	AR	42,100	83,300	22.6	45.8
A-285	AR	21,200	50,100	37.0	66.8
	N	33,000	51,600	38.2	69.5
A-302(H)	AR	67,000	95,400	20.2	66.2
	N	47,700	85,600	26.8	62.2
A-302(B)	MN	52,000	83,300	22.1	55.8
48s5	MN	47,300	68,300	29.8	67.2
T-1	Q&T	114,000	123,600	13.9	57.5

AR, As-rolled. N, Lab. normalized. MN, Mill normalized. Q&T, Quenched and tempered.

with the longitudinal axis parallel to the plate rolling direction. Longitudinal weld beads were deposited automatically using the electrodes and conditions noted in Table 3. A standard 6 ipm electrode travel speed was used.

After notching transversely to a depth of 0.040 in. with a standard V-notch cutter, Kinzel specimens were tested using an 11-in. span and a loading rate of 2 ipm. Each specimen was measured for lateral contraction at the notch root before and after testing and the fracture pattern of each specimen was analyzed.

The transition temperature for a Kinzel series was chosen in two ways: at 1% lateral contraction and also at what will be termed the "nil-shear" temperature. The nil-shear transition is the temperature below which a cleavage crack initiated in the weld zone (weld metal or heat-affected zone) is able to propagate without interruption through essentially the entire specimen. Above this temperature the *base* material is able to prevent cleavage crack propagation by changing the crack to shear. The fracture patterns of specimens exhibiting this behavior reveal a ring or band of fibrous appearance in the base metal. The nil-shear transition is, therefore, a measure of base metal notch toughness with respect to its cleavage-crack propagating ability. It is to be noted that the nil-shear transition can be measured only when the weld zone supplies a cleavage crack initiator effective to temperatures at least slightly above the nil-shear temperature. It has been found that "as-welded" Kinzel specimens almost always exhibit the above behavior, and, as a result, a measurement of the nil-shear transition was possible on all series tested in this project. (Postheating generally reduces the effective temperature range of the weld zone cleavage crack initiator to temperatures below the nil-shear transition.)

Table 3—Welding Electrodes and Conditions

Steel	Electrode	Arc volts	Amperes
A-302	E9010	28	180
48s5	E7015	28	180
T-1	E12015	22	200
Balance	E6010	28	180

Drop-Weight Crack Starter Tests

Drop-weight specimens were cut with the longitudinal axis parallel to the plate rolling direction. Specimens were welded using "Hardex-N" hard-surfacing electrodes with automatic feed, 6 ipm travel speed, and 200 amp and 22 arc volts. After welding, the specimens were notched to a depth of 0.070 in. above the plate surface using a V-notch Charpy milling cutter.

Specimens were tested over a range of temperature to determine the nil-ductility transition temperature; i.e., the temperature below which the steel did not deform prior to fracturing. In the drop-weight test the hard facing weld deposit supplies a running cleavage crack to the base metal when the stresses at the surface of the specimen reach the yield point of the steel being tested. Depending upon the test temperature, the steel may or may not offer resistance to propagation of this crack. If no resistance is offered, the specimen will break cleanly with little evidence of plastic deformation. If cleavage crack propagation is resisted, the specimen will not break completely before it hits the stop, and plastic deformation will be evident.

It is said that the heat-affected zone surrounding the hard weld bead does not influence the test results. In order to allow this to be checked, all drop-weight specimens were broken apart after testing in order to observe by examination of the fracture surfaces the extent of cleavage crack propagation.

Results and Discussion

Table 4 is a compilation of the transition temperatures for all steels in all conditions as determined by the three testing methods. It will be noted first that in almost all cases the Kinzel 1% lateral contraction transition and the nil-shear transition correspond very closely. The nil-shear transition, it will be remembered, is the temperature above which the base material can prevent the propagation of a weld-zone

Table 4—Transition Temperatures, °F, Obtained by Four Testing Methods

		Kinzel		Drop weight,	V-Charpy,
Steel	Condition	1% lat. cont.	Nil-shear	NDT	10 ft-lb
A-7(RW)	AR	+20	+15	+5	+15
	N	+5	+5	+5	−10
A-7(W)	AR	+20	+20	+35	+60
	N	+25	+10	+25	+35
A-201(RB)	AR	−30	−30	−5	+15
	N	−20	−20	−10	−30
A-201(Y)	AR	+10	+10	+10	+10
	N	...	...	−20	−25
A-212(KC)	AR	+25	+15	+15	+10
	N	+5	+5	+5	−20
A-212(T)	AR	+50	+25	+35	+60
A-285	AR	−15	−15	+5	+35
	N	−15	−15	−15	+10
A-302(H)	AR	+100	+100	+55	+10
	N	...	...	−20	−25
A-302(B)	MN	+20	...	+5	−35
48s5	MN	−20	...	−15	−60
T-1	Q&T	−80	−80	−85	−210

AR, As-rolled. N, Lab. normalized. MN, Mill normalized. Q&T, Quenched and tempered.

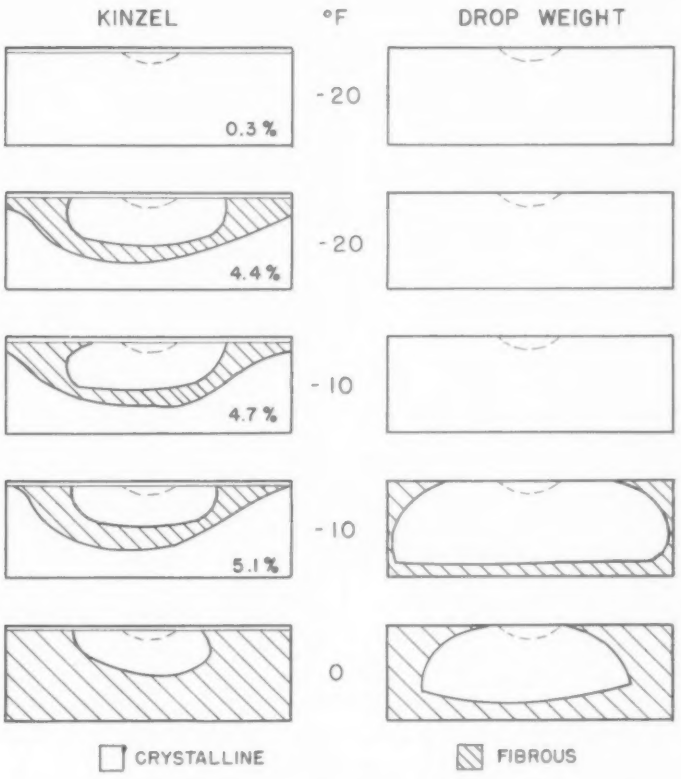

Fig. 1 Typical fracture patterns for Kinzel and drop-weight specimens tested through the transition range

initiated cleavage crack and thus produce some shearing. This base metal shear almost always produces a lateral contraction close to or above 1%; thus the correlation between 1% and nil-shear transition.

Correlation Between NDT and Kinzel Transition

In Fig. 1 are drawn the fracture patterns for Kinzel and drop-weight specimens for a representative steel tested over a range of temperature. These patterns indicate for each specimen the extent of cleavage and shear (crystalline and fibrous appearance) produced during failure. In the Kinzel series at −20° F, a cleavage crack was initiated in the weld zone and propagated through essentially the entire specimen. In another specimen tested at −20° F, the cleavage crack could not propagate completely through the specimen but changed to shear in the base metal. Upon additional loading, cleavage once again initiated and propagated through the specimen. Shearing in the base metal caused the lateral contraction to rise above 1%. For the Kinzel series the 1% lateral contraction and nil-shear transitions are both placed at −20° F.

For the drop-weight series, the nil-ductility transition (NDT) temperature was found to be at −10° F. At and below −10° F the cleavage crack initiated by the hard-surfacing deposit ran completely through the specimen. Above −10° F., complete propagation of this crack was prevented by the base material. In this instance a "stop" beneath the specimen prevents complete fracture. The fibrous areas in the drop-weight fracture patterns were produced *after* testing when the specimens were broken apart in order to observe the extent of cleavage crack propagation.

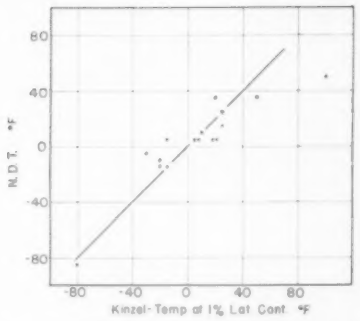

Fig. 2 Correlation between NDT and Kinzel 1% lateral contraction transition temperature

The similarity between the fracture patterns of the Kinzel and drop-weight series is obvious. In both series the resistance of the base metal to cleavage crack propagation is being measured.

It seems logical to assume, therefore, that the Kinzel 1% lateral contraction and nil-shear transitions should correlate with the drop-weight nil-ductility temperature. In Fig. 2 the Kinzel 1% lateral contraction temperature is plotted vs. the NDT. The line shown is drawn at a slope of 1 and the clustering of data on and near this line indicates that an approximate 1 to 1 correlation between this transition temperature does exist. It must be remembered however that this comparison is

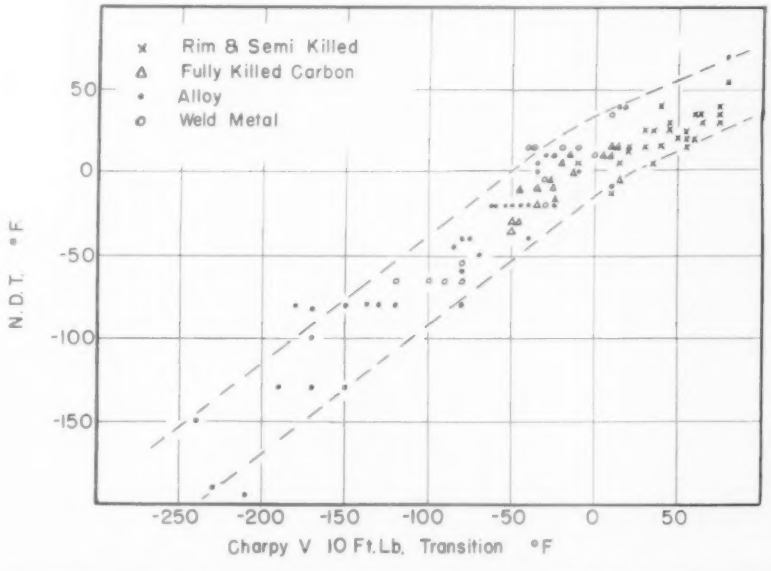

Fig. 3 Correlation between NDT and V-notch Charpy 10 ft-lb transition temperature

valid only because, for the particular steels plotted, the 1% lateral contraction temperature is controlled by the ability of the *base material* to prevent cleavage crack propagation.

Correlation Between Charpy-V Transition and NDT

In Fig. 3 the NDT is plotted vs. the V-notch Charpy 10 ft-lb transition temperature for a wide variety of steels and heats. These data include the results from the present investigation and results culled from various papers by Pellini and associates[1-5] at NRL. It is apparent from these data that a scatter-band exists within which the two transitions correlate. The slope of this band is less than the 45 deg which would indicate a 1 to 1 correlation between the NDT and Charpy 10 ft-lb transition temperature. Therefore, for steels with low transition temperatures, the 10 ft-lb transition falls at temperatures substantially lower than the NDT while the opposite is true for steels with poor notch toughness. This correlation reveals one reason for the concept developed by Pellini and associates at NRL that for "different types" of steel it is necessary to use different energy levels in order to obtain a direct correlation between the NDT and the Charpy transition. Thus, "high-strength" steels require an energy level higher than 10 ft-lb for correlation with the NDT because, in general, they possess good notch toughness, i.e., they fall in the low-temperature range of the band in Fig. 3. Also the higher strength steels absorb more energy at a given ductility because of the greater force required to break them.

In general, therefore, as notch toughness increases, the V-notch Charpy transition temperature will fall faster than the NDT. This is revealed graphically in Fig. 4, which shows the decrease in Charpy-V transition and nil-ductility-transition temperatures obtained by laboratory normalizing six of the project steels. In all cases, normalizing resulted in an improved notch toughness according to the Charpy test. However, normalizing always reduced the 10 ft-lb temperature more than the NDT. In fact, in one case [A-7(RW)] the NDT did not change at all when the Charpy transition temperature dropped 25° F.

Effect of Postheat on Drop Weight NDT

In order to determine whether the heat-affected zone could be made tough enough to influence the NDT, drop-weight specimens of several steels were given a stress-relief postheat at 1150° F after welding. Results of drop-weight tests on these specimens are reported in Table 5. It is seen that for four of the steels there is effectively no change in the NDT but that the A-302 steel shows a drop of 105° F in the NDT. Previous work has shown that the notch toughness of this steel in the unwelded condition is changed very little by postheating at 1150° F. Therefore, the change in NDT must be due to metallurgical improvement of the heat-affected zone. Previous work has also shown that for this heat of A-302 steel welding heat inputs corresponding to those used in depositing the brittle weld bead will produce in that area of the heat-affected zone directly beneath the fusion line a microstructure consisting wholly of low-carbon martensite. Subsequent tempering of this structure results in an extremely tough material with a Charpy V-notch 10 ft-lb transition temperature of approximately −200° F. It seems reasonable to assume therefore that this very tough structure prevents propagation of the brittle weld initiated cleavage crack at temperatures above −50° F. Below −50° F this zone is no longer tough enough to inhibit propagation in the drop-weight test and the specimen behaves as if it were below the NDT.

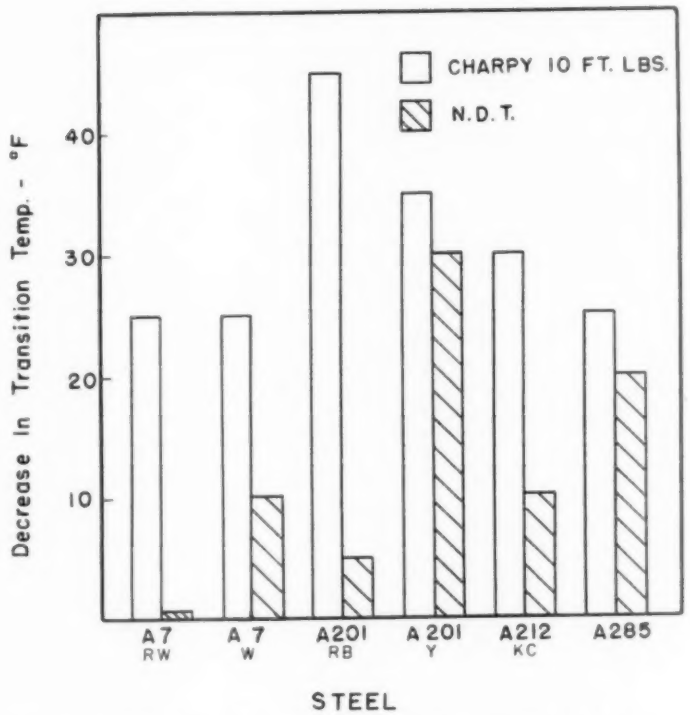

Fig. 4 Comparison of decrease in transition temperature due to normalizing for Kinzel and drop-weight tests

Table 5—Effect of Postheat on Drop Weight NDT, °F

Steel	*Condition*	*Standard NDT*	*Postheated NDT*
T-1	Q&T	−80	−90
A-302	AR	+55	−50
A-212(KC)	AR	+15	+20
A-7(W)	AR	+35	+45
A-7(RW)	AR	+5	+15

The above results were further substantiated by examination of the fracture surface of those postheated drop-weight specimens of A-302 steel tested above the NDT. This examination revealed that in all cases the cleavage crack initiated in weld metal was stopped at the fusion line, i.e., was prevented from entering the base metal by the tough heat-affected zone.

The results presented above indicate that it is possible under some conditions to obtain an NDT which is not controlled by the ability of the base metal to resist cleavage crack propagation. In the present investigation the condition was artificially imposed by a stress-relief postheat following welding of the test specimens. In normal testing practice this, of course, would never be done. Nevertheless the possibility does exist that in some steels welding by itself might produce a heat-affected zone tough enough to lower the measured NDT appreciably below the actual NDT of the base material. It is to be emphasized that this situation is probably uncommon.

Effect of Loading Rate on NDT

Tests were conducted on several steels to determine the effect of loading rate on the drop-weight transition temperature. For these steels standard drop-

Table 6—Effect of Loading Rate on NDT

Steel	Condition	Standard NDT, °F	Slow-Bend NDT, °F
A-7(RW)	AR	+5	−35
A-201(RB)	AR	−5	−60
A-285	AR	+5	−60

weight specimens were tested to failure in slow bending in the same way that the Kinzel specimens were tested. In order to maintain the same transition criterion for the slow-bend tests as for the dynamic tests, the specimens were assumed to have failed only when they fractured completely before a deflection of 0.3 in. was reached. Results of the slow-bend tests using drop-weight specimens are reported in Table 6 where it is seen that slow bending produces a transition temperature 40 to 65° F below the standard NDT.

Conclusions

1. There is an approximate one-to-one correlation between the nil-ductility transition as determined by crack starter drop-weight tests and the Kinzel 1% lateral contraction transition. This correlation is valid only for those steels in which the behavior of the Kinzel specimens tested above the transition temperature is one in which the propagation of a weld zone initiated cleavage crack is inhibited by the base material.

2. For most of the structural steels tested, the Kinzel 1% lateral contraction transition temperature was a manifestation of the ability of the base material to inhibit propagation of a weld-zone-initiated cleavage crack.

3. A plot of NDT vs. Charpy 10 ft-lb transition for a large number of steels revealed a scatterband within which the two transition temperatures correlated. The slope of the band is such that for steels with good toughness, i.e., low transition temperatures, the NDT is appreciably higher than the Charpy 10 ft-lb transition, while the opposite is true for steels with relatively poor notch toughness.

4. For the steels tested here, fracture examination of standard drop-weight specimens indicated that the NDT was a true measure of base-material properties and was not influenced by the heat-affected zone beneath the weld. However, experiments on post-heated drop-weight specimens indicate the definite possibility that for some steels the heat-affected zone influences the NDT.

5. Decreasing the loading rate by testing drop-weight specimens in slow bending lowered the NDT by 40 to 65° F.

Acknowledgment

The investigation reported here was under the guidance of the Weldability Committee of the Welding Research Council and was supported with funds from the American Iron and Steel Institute. The authors are grateful for the assistance of both of these organizations.

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WELDING HEAVY SECTIONS BY THE RUSSIAN ELECTRO-SLAG PROCESS (*Continued from page 306-s*)

Table 4—Fluxes for Electro-Slag Welding

Grade	SiO_2	Al_2O_3	MnO	CaO	MgO	$Na_2O + K_2O$	FeO	CaF_2	S	P
AN8	33–36	11–15	21–26	4–7	5–7	..	<1.5	13–19	<0.15	<0.15
AN22	18–21.5	19–23	7–9	12–15	11.5–15	1.3–1.7	<1.0	20–24	<0.15	<0.15
FZ7	46–48	<3	24–26	<3	16–18	0.6–0.8	<1.5	5–6	<0.15	<0.15

recommended for alloy steel and melts at 1940° F. AN8 and FZ7 develop sufficient SiF_4 to prevent porosity in welding rimmed steel.

Welding wire suitable for submerged-arc welding is used. For example, the wires for plain carbon steels contain 0.10–0.18% C, 0.35–1.10% Mn and 0.03% Si. The standard electro-slag welder A372M is stationary, accommodating three coils of wire. The water-cooled molds are held by springs attached to the apparatus. Mobile welders A340 and A350 also are available. The equipment weighs 660 lb and requires 2200 lb force to hold it to the vertical plates. Welder A340 accommodates one wire; A350 feeds three wires. There is also an electromagnetic welder A411 which is held to the plate by magnetic force, and "walks" up the joint by eccentric action. The catalog describing this apparatus is printed in Russian and English, and is published by Maschinoexport, Moscow.

Mechanical Properties. About 20% of the weld consists of melted base plate. Table 5 shows the composition of weld metal deposited in boiler plate 3.6 in. thick with flux FZ7. Weld metal deposited by wire containing 0.25–0.35 C, 0.8–1.1 Mn, 0.9–1.2 Si, 0.8–1.1 Cr had 162,000 psi yield strength, 173,000 psi tensile strength, 10.8% elongation, 36% reduction of area. The process also is used to weld stainless steel and high-speed tool steel.

Table 5—Chemical Composition, %, of Boiler Plate, Wire and Weld

	C	Mn	Si	S	P
Boiler plate 22K	0.18	0.81	0.29	0.022	0.021
Wire Sw-08GA	0.09	0.96	0.04	0.028	0.017
Weld metal	0.13	0.81	0.12	0.023	0.019

Table 6—Mechanical Properties of the Weld in Table 5

	As-welded	Normalized†
Yield strength, psi	37,000–42,000	32,700–37,000
Tensile strength, psi	64,000–64,800	60,500–66,500
Elongation, %	22.5–32.6	53.0–66.5
Reduction of area, %	29.0–34.0	58.0–67.5
Notch impact value, mkg/cm²*	12.7–16.3	8.1–16.7

* After strain aging (10% compression, then 2 hr at 480° F) the notch impact value fell to 0.9–12.0 mkg/cm².

† Heated 45 min at 1650–1670° F, then heated 2 hr at 1200–1240° F, cooled in air.

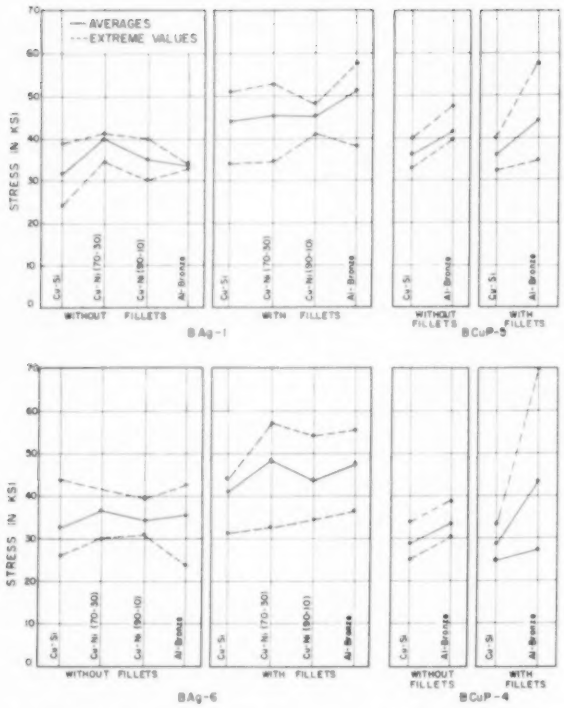


Fig. 17 Effect of base metal on strength of lap joints

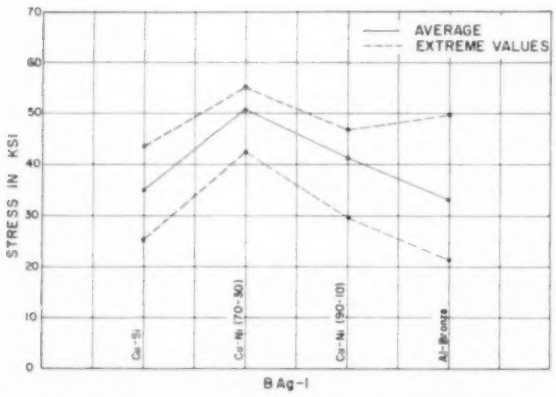


Fig. 18 Effect of base metal on strength of butt joints

Additional Figures

The three illustrations shown herewith, namely, Figs. 17, 18 and 19, should be added to the following article which appeared on page 177-s through 184-s of the April 1957 issue of The Welding Journal Research Supplement:

STRENGTH OF BRAZED JOINTS IN COPPER ALLOYS

by W. H. Munse and J. S. Alagia

The Editor

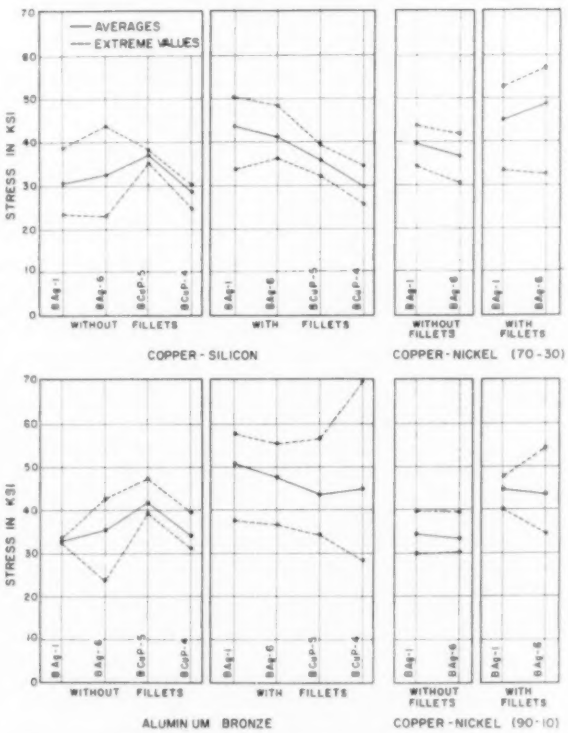


Fig. 19 Effect of filler metals on strengths of lap joints

WELDING ROD CLINIC

J. Imperati and R. F. Pulver, Welding Engineers
The American Brass Company, Waterbury, Conn.

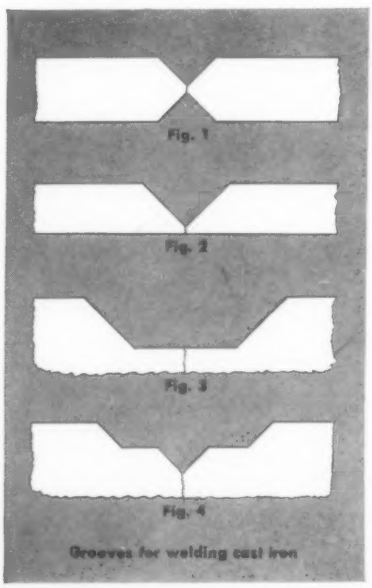
How to Braze-Weld Cast Iron

Practical suggestions for making strong, lasting repairs

Cast iron is economical and useful for many purposes, despite its disadvantage of low ductility. However, this low ductility is a major obstacle to success when fusion-welding is attempted for repairs, because shrinkage stresses often cause failure of the welds.

Oxyacetylene braze-welding with Anaconda-997 (Low-Fuming) Bronze and Tobin Bronze-481 Welding Rods is widely recognized as the easiest and least expensive repair method. The reasons are 1.) the low temperatures employed do not produce embrittlement or excessive stress in the joint area, and 2.) the ductility of the bronze weld metal permits it to yield and prevents development of high stress.

Correct preparation of the fracture is necessary to realize all the advantages of braze-welding. As with all other welding processes, the break must be opened up to permit bonding of a sufficient thickness of the casting. Although the double-vee of Fig. 1 is the most economical in consumption of weld metal, and is often used when sections are not too heavy, the simplest preparation is the single-vee groove of Fig. 2. In either case, the bronze weld metal is applied to both sides for maximum joint efficiency. A small section of the fracture is left intact, as shown, to assist in lining up the parts.



Grooves for welding cast iron

In heavy secuons which cannot be opened up for the full thickness, the area bonded by bronze can be increased, in order to develop higher joint strength, by use of the wide-bottomed vee of Fig. 3. The same results can be obtained, with use of less bronze, in the shear-vee joint of Fig. 4.

Joints can be beveled by chipping, machining, filing, or grinding, in order of preference. Graphite smeared into the surfaces by grinding will interfere with bonding, but even ground surfaces can be used safely if they are first heated to a dull red with an oxidizing flame and wire-brushed thoroughly.

Oil on the joint surfaces will interfere with bonding, and should be removed. In most cases, a solvent will do this well enough. However, if heavily soaked, the castings should be preheated to temperatures between 600 and 1200F until most of the oil is removed, which would be when the smoking stops.

Preheating also facilitates welding on large castings where it is difficult to maintain the required heat level by means of the welding torch alone.

The most important function of preheat is to control expansion of components and avoid excessive stressing in complex castings like wheels, gears and frames. Where the whole casting is not heated, selected sections are heated to assist in opening up the fracture; then they shrink with the joint as it cools. Simple examples are shown in Fig. 5.

Fluxing is essential to insure proper bonding and sound joints. Suitable braze-welding fluxes are available from many sources. The flux should be sprinkled on the joint areas during the heating-up period. An efficient way to use flux is to dissolve it in boiling water and paint it lightly on the cleaned rods. It sticks well to the rods, keeps them from oxidizing, and eliminates the need to dip the rod end constantly in the dry flux.

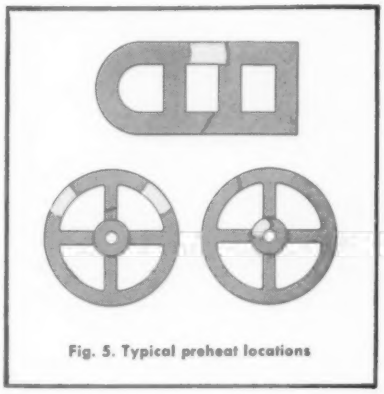


Fig. 5. Typical preheat locations

A slightly oxidizing flame adjustment is preferred. Torch-tip sizes should be selected so that the bronze melts and flows as required without having to apply the flame's inner cone to the weld pool. The intense heat of this inner cone causes heavy fuming and severe oxidation of the joint surfaces. Prolonged heating, or "puddling," of the weld metal should be avoided, as it wastes time and gases, and impairs the bond to the iron.

For More Information. Anaconda distributors will gladly help in the selection of the exact rod for your job. Or write for a copy of Publication B-13. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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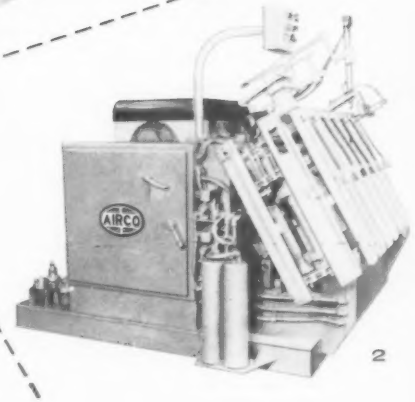

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